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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 355

Contribution from the States Relations Service
A. C. TRUE, Director

Washington, D. C. April 13, 1916

EXTENSION COURSE IN SOILS.

By A. R. WHITSON, *Professor of Soils, University of Wisconsin*, and H. B. HENDRICK, *Assistant in Agricultural Education, States Relations Service.*

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GENERAL SUGGESTIONS TO LEADERS.

Although it is not necessary that the leader of this course shall have had any special training, his work will be easier if he reads at least a lesson ahead of the class work, or, better still, goes more or less rapidly through the whole bulletin in advance. In this way it will be easier for him to make suggestions regarding the practice work in connection with each lesson.

The references of each lesson have been carefully selected and are thought to be about sufficient to utilize the remainder of the forenoon after the lesson text has been carefully read and discussed. Where a choice is given between two references, the leader may use his judg-

NOTE.—This course has been prepared by direct cooperation between the authors and J. M. Stedman, Farmers' Institute Specialist, of the States Relations Service, and is designed to aid agricultural colleges in their extension work. It is intended for the use of small groups of farmers assembled as a class to study the subject in a systematic manner with one of their number as a leader. It is adapted for use in any part of the United States. The agricultural college is to loan the class the reference library listed in the Appendix and also a set of apparatus and the supplies designated therein. The class meets as often as convenient in a suitable room where tables for exercise work are available. The forenoon is devoted to the lesson and reference work and the afternoon to the exercise work, an entire day being thus consumed for each lesson. At the completion of the course and as often as desired the college conducts examinations through the leader and corrects and returns the papers.

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ment as to which will be most profitable for the class to read. No attempt should be made to read tables of record data, but many of these can be carefully studied by the class and conclusions called for by the leader. If in any lesson the references should be too short, it will be easy to select others from the reference library; if, on the other hand, they should prove to be too long, the leader can cause certain parts of least importance to be omitted.

The exercise equipment and supplies should be put away, and only such parts of them as are needed for the exercise in hand should be handled or used during the period. The leader should make himself responsible for this practice by the class.

The queries at the end of each exercise are intended to aid in fixing the leading points of the lesson in the minds of the members and should be conducted at the close of the practicum work. The majority of the questions have to do with facts brought out in the lessons, but some of them refer to matters which the class is expected to have gathered from experience and thought.

LESSON I. ORIGIN, FORMATION, AND COMPOSITION OF SOILS.

The intelligent use and management of the soil is based on an understanding of its structure and composition. A good soil consists largely of two parts: (1) The *organic* matter derived mainly from plants which have previously grown on the land and have decomposed more or less, but also to some extent from the remains of animal life; (2) *inorganic* or mineral matter, derived originally from rocks. If soil is burned at a red heat, the organic matter is burned off, leaving the rock material. The organic part is the principal factor contributing to the dark color of soils. The inorganic is that derived from the rock and is made up of particles of all sizes from coarse sand or gravel down to those so minute that they can not be seen by the naked eye. Both the organic and the inorganic matter play important parts in determining soil fertility.

ORIGIN OF SOIL.

Rocks and minerals as soil factors (Ref. No. 3, pp. 1–3, 7–12).—Minerals are the substances of which rocks are composed and constitute the inorganic part of soils. Some familiar minerals are gypsum or land plaster, and calcite, which occurs in marble and limestone. Some of the most common rock-forming minerals are quartz, feldspar, hornblende, and mica. White sand is nearly pure quartz. The fertility of the soil is closely related to the minerals which it contains.

Rocks are masses of minerals, physically united, and form a considerable portion of the earth's crust. Geologically rocks are grouped with regard to their origin and structure. The most important group, agriculturally, are the aqueous rocks, so-called because they

are believed to have been formed mainly through the agency of water. Examples of one class of these rocks are the deposits of gypsum and phosphate beds. The most important classes of the aqueous rocks, however, are those of sedimentary origin. They are composed of the materials resulting from disintegration of older rocks and from the mineral remains of animal and plant life. These rocks are largely distributed over the earth's surface and include the limestones, the sandstones, and the shales.

Organic matter as a soil factor (Ref. No. 7, pp. 120–125).—The organic matter of the soil has many important relations to the soil's fertility. Vegetable matter, commonly in the form of leaves, and of stems and roots of plants which have died, undergoes a process of decomposition in which it breaks down into simpler substances. When moisture and the air have ready access to it, vegetable matter slowly decomposes into the substances which were taken by the plant, in growth, from the soil and those which were absorbed from the atmosphere. The process is much the same as though the vegetable matter were slowly burned, and, like burning, it produces volatile gases and mineral ash, which again serve as plant-food materials. However, when the air does not have ready access to the decomposing vegetable matter, it undergoes much slower and often different changes, yielding residues known as humus, muck, and peat.

Humus may be defined for present purposes as vegetable matter in such an advanced stage of decomposition as to have lost its original physical identity. The degree of fertility of soils is very closely related to the amount of humus which they contain, and one of the most important problems of a farmer is to manage his soil so as to retain a high humus content. The quantity of vegetation returned, the drainage, the temperature, and the character of the soil are conditions affecting humus content. Peat and muck are terms applied to vegetable matter which has undergone changes under water, largely without air, and which may be in various stages of decomposition. Marsh soils are largely composed of muck and peat.

FORMATION AND COMPOSITION OF SOILS.

Agencies of soil formations.—The principal agencies which have formed soils from rocks and organic matter may be classified as physical, chemical, and biological. (Ref. No. 9, pp. 1–6.)

A physical change in matter is one which does not produce a substance or substances of different composition. For example, the changes of water to ice or to steam are physical. The form of the matter is changed, but not the composition. Likewise, the dissolving of salt in water produces a physical change. The physical

agencies which have most affected the formation of soils are temperature changes, or heat and cold, water, ice, and wind.

A chemical change, or reaction, is one which separates or rearranges the elements of a substance or compound. Chemically, an element is a single substance which can not be separated into two or more different substances; a compound is a union of two or more elements in certain definite proportions. Gold, silver, quicksilver, oxygen, and nitrogen are examples of elements. There are about 80 known elements. Common salt is a compound of the elements sodium and chlorin; water is a compound of the elements hydrogen and oxygen; carbon dioxid, present in the air, is a compound of the elements carbon and oxygen. The formation of carbon dioxid in the decomposition of vegetable matter and the uniting of this gas with other substances to form carbonate compounds, are common examples of chemical changes in the soil.

A biological change is one resulting from plant or animal life within the soil and may affect soil substance physically or chemically. Insect life in the soil is a matter of common knowledge. When plant or animal organisms are so small that they can be identified and studied only by the use of the microscope, they are called microorganisms, and a study of those commonly occurring in the soil is called soil microbiology or soil bacteriology. Nitrification, or formation of nitrates, is a typical example of microbiological (bacterial) changes in soils. The work of nodule-forming bacteria upon the roots of red clover, alfalfa, and other leguminous plants, is another example of such changes affecting the productiveness of soils. The biological changes produced in the soil are very extensive and important. See Lesson VI.

The physical, chemical, and biological factors which have been potent agencies in the formation of soil for past ages are constantly producing soil changes. Their action may be advantageously controlled to some extent by the farmer, as will be shown in other lessons.

Residual soils (Ref. No. 3, pp. 31–35).—Soils formed from the rocks immediately underlying them are called residual soils. On examining a stone quarry, it is usually found that the upper portion of the quarry rock is more or less broken up and pieces of the rock are embedded in the lower layer of the soil. In fact, the finer pebbles and cobbles of stone often extend all the way to the surface of the soil. A careful study will show that the soil itself has really been formed from the rock. This has resulted from the action of several agencies. Among them the expansion and contraction of the rock due to alternate heating and cooling are very important. The expansion of water as it freezes has much the same effect. During the long period of transition from solid rock to thoroughly disintegrated rock,

or soil, the percentage composition of materials may be somewhat changed by the difference in solubility of the compounds forming the rock, and by other factors. Because of the wide variation of rocks forming residual soils and the changes which may take place during rock disintegration, these soils are of many kinds.

Granite rocks consist principally of the minerals feldspar, quartz, hornblende, and mica. In the decomposition of granites carbon dioxid, usually called carbonic acid, dissolved in soil water, combines with the elements potassium, sodium, or calcium in the feldspar, forming soluble carbonate compounds of these elements, while insoluble alumina and silica, uniting with small quantities of water, collect as clay. Quartz grains, on the other hand, are not appreciably affected by carbon dioxid, and so collect as sand in the soil. In this way there is formed from granites a mixture of clay, sand, and partly decomposed particles of all the minerals found in the granite rocks.

Soil is also formed from limestone rocks by weathering and solution. Limestone consists principally of calcium and magnesium carbonates. These slightly soluble carbonates are made more soluble through the action of carbonic acid in the water of the soil. A good illustration of such solution is the so-called hard water from a limestone well. When such water is boiled the carbon dioxid holding the calcium carbonate in solution is driven off and the carbonate is precipitated as a solid residue which often adheres to the containing vessel, forming what is known as scale. In soil formation from limestones, as the carbonates are dissolved and leach out, the impurities in the limestone, chiefly fine clay and silt, are left to collect and form a soil. Mixed with this fine residual clay and silt is usually found a great deal of stony material consisting largely of silica, and known as flint or chert. Soils formed from limestones are, therefore, largely clay, containing more or less flint or chert.

In the formation of soils from sandstone rocks the changes taking place are largely physical, and the composition of the soils differs but little from that of the rocks from which they are derived. The chief process is the disintegration of the rock and the separation of the sand grains through freezing and thawing and the action of water. Soils formed in this way from sandstones are, of course, sandy in character, though they may be somewhat finer than the rock itself, since the grains of sandstone not only separate one from another, but split up into somewhat finer parts.

The principal area of residual soil in the United States is south of a line extending roughly from New York to Pittsburgh, thence following the Ohio River to the Mississippi River, up the Mississippi and Missouri Rivers to the Dakotas, and from thence west to the Puget Sound region in Washington, where it turns well southward. From this area, however, should be excluded the coastal plains,

deposits which, in the South Atlantic and the Gulf Coast regions, have an average width of over 100 miles and which are not residual soils, but there should be added numerous small areas of residual soils scattered throughout areas of other kinds of soil.

Cumulose or swamp soils (Ref. No. 3, pp. 35–38).—This type of soil is related to residual soils in that it has been formed largely from materials not transported. When plants grow where water fills the soil most of the time, the lack of air in the land surface hinders the decay of organic matter to the extent that large deposits of this material finally collect. Such accumulations going on for ages result in what are commonly known as peat bogs or muck swamps. They contain, as a rule, only such mineral matter as has been washed in from adjoining areas. Cumulose soils are widely distributed and vary greatly in area. In this country they are most numerous in the northern United States, while larger areas of slightly different type, known as seacoast swamps, are common along the Atlantic and Gulf coasts. Such soils are generally useless for agricultural purposes until drained. The management of marsh soils, however, is considered in Lesson X.

While soil in many cases has been derived as above explained from the rock directly under, or from plant remains in place, there are many kinds of soil which were formed in other sections of the country and have been brought to their present location by some natural agency. The three most important agencies transporting soil materials are water, ice, and wind.

Alluvial soils (Ref. No. 2, pp. 43–50).—The action of water as a soil-forming agent is a matter of common observation. Whenever streams flood and overflow their banks they deposit some of the sediment brought down from higher up in their valleys. In this way they frequently form layers of sand or fine gravel when the stream is rapid, and of silt when it is moving very slowly, and in the broad, lakelike floods which occupy the larger valleys of the more important rivers the finest sediment, or clay, is frequently deposited in deep layers. Soils thus transported by water are called alluvial soils. They are always stratified, and the strata frequently vary a great deal in the size of grains, so that a layer of gravel is often found under one of coarse sand, and a layer of coarse sand under one or more of fine silt. For this reason alluvial soils differ greatly in character, and one must examine the subsoil of any alluvial field if he desires to know its condition and value. Alluvial soils include large agricultural areas, and when well drained are among the most productive soils of the earth's surface. The high percentage of organic matter which they commonly contain and the frequent renewing of fertility by repeated overflows (in case of the low-lying alluvial soils) are reasons why they keep productive. The Nile Valley in Egypt is a

notable example of alluvial deposit regularly renewed. Large soil areas of this nature are common in the valleys of the Mississippi River and its tributaries, and those of smaller extent are common in the northern United States.

Glacial soils (Ref. No. 2, pp. 54–61).—In lands far toward the poles snow accumulates to great depths, and its pressure becomes such as to compact it into immense fields of ice. Where sloping land surfaces or valleys occur, the force due to gravity causes these sheets of ice, called glaciers, to move slowly down the inclines, grinding the rock surfaces and carrying along large bowlders and much soil material. When the ice front of winter begins to melt and recede, as summer approaches, there is left a layer of miscellaneous ground rock materials whose position has been more or less affected by the carrying properties of the water formed by the melting ice. Such formations of soil are constantly being produced in the Arctic and Antarctic regions. This condition illustrates a period in recent geological times when immense sheets of ice moved over the land surface of the earth, in both Northern and Southern Hemispheres, much beyond the present limits of perpetual snow. Soils formed as the result of the action of glaciers during this ice age are called glacial soils. (Ref. 3, p. 52.) In the United States soils of glacial formation extend approximately to the line described as the northern boundary of residual soils, page 5.

It is easy to understand how the character of glacial soils may vary widely even within the limits of small areas, since they are composites of all the rock materials over which the ice sheets have passed. Where the ice moved across granite rocks it mixed the residual soil previously formed from the granite with cobbles and bowlders brought from farther north. The granite rock itself was too hard to be much affected by the ice, though it was often polished quite smooth. On the other hand, when the ice sheets passed over areas underlain by sandstone, which is much softer than granite, the rock was ground up and formed into a sandy soil of rolling topography. The chemical composition of the soil, however, like residual soils from the sandstone, was not much changed. The ice in passing over limestone country ground up a good deal of the limestone underlying the surface residual soil, mixing it with the surface and forming a soil richer in limestone, or calcium carbonate, than the corresponding residual soil. The glaciers in their movement often filled up valleys and in many cases left shallow basins which filled up with water until an outlet was found. The region which was covered by glacial ice is characterized, therefore, by a large number of small lakes and marshes since formed in lake beds. When the glacial sheets receded, the water flowing from the melting ice carried with it the sedimentary materials ground up in the ice, producing fanlike plains

and frequently filling valleys beyond the ice border with gravel, sand, and finer sediment to a depth of from 50 to 200 feet.

Glacial soils, as would be supposed, vary widely in their productive capacity, and the management of soils within the glacial area is often difficult because of the wide differences in soil types which may occur even within the boundaries of a single farm.

Wind-formed soils—Loess (Ref. Nos. 2, pp. 68–69; 3, pp. 59–61).—It is a familiar fact that the atmosphere carries suspended a considerable quantity of fine dust particles and that after rains and snows the air is left clearer because much of the dust has been carried to the earth by the falling raindrops or snowflakes. During high winds, when the land surface is dry and not covered by vegetation, the air frequently becomes so laden with fine soil that one can see for only a short distance. Where windbreaks occur these soil grains are often deposited in large quantities, forming soil drifts of varying character. The sand dunes bordering the shores of the Great Lakes are of wind formation. On the Great Plains of the western United States, where the soil is dry and heavy winds are common, considerable damage is often done to farms by the transportation and drift of soil from place to place.

Loess is a type of soil of a fine, silty composition, which commonly contains a considerable amount of calcareous materials. Loess has a peculiar ability to stand in nearly vertical walls when eroded by wind or stream. Such soils are unusually uniform, both in physical and mineral composition, and possess high natural fertility. An extensive area of typical loess soil is found in the Chinese Empire, where the material, as above described, extends to the depth of 1,000 feet or more. This immense deposit is generally believed to have been transported by the wind. The so-called loess soil of the United States, however, extending over much of the Mississippi Valley, is commonly believed to have been transported largely by water. Its depth varies from a few feet in the outer edges of the area to 150 feet, or more, in the more central portions.

EXERCISES, LESSON I.

Materials needed.—Samples of typical soils found in the community, including marsh soil, if any; hand lens; long pickle bottles with corks; a few pieces of rock candy (this can be secured at the local store); specimens of common rock, such as granite, trap rock, schist, shale, slate, limestone, marble, sandstone, and quartzite; specimens of common rock-forming minerals—feldspar, hornblende, quartz, black and white mica, calcite, and gypsum.

ROCKS AND MINERALS.

(a) Examine carefully the rock-forming minerals—feldspar, quartz, hornblende, mica, and calcite. Compare relatively their weight, then note color and plane or direction of cleavage of each, after which determine their relative degree of hardness. The relative hardness can be determined by scratching each with the others.

Which are the two most common rock-forming minerals of the earth's crust?

(b) Examine with the lens the different rock samples—granite, trap rock, schist, shale, slate, limestone, marble, sandstone, and quartzite. Compare these with the mineral samples and try to determine from which minerals the rocks were largely formed. What kind or kinds of soil are formed from granite? From sandstone? From limestone? From shale and slate?

PHYSICAL AND CHEMICAL CHANGES.

Examine a piece of rock candy, noting color, crystalline form, hardness, and taste. Grind a piece to powder with the mortar and pestle. Has the taste changed? Dissolve a little of the powder in a small quantity of water. Taste the liquid to determine if the material still exists. The changes thus far have been physical changes. Now heat a little of the powder in a dish, slowly first, noting all the changes. Heat until no further changes take place, then allow to cool. Taste the residue. Note its color. What does the new substance resemble? Will it dissolve in water? What kind of a change has taken place?

SOIL COMPOSITION.

Material composing soils.—Examine carefully (hand lens may be used) several samples of soil in the field or classroom and note their physical make-up. Distinguish between *organic* and *inorganic* particles, between vegetable and mineral matter. Which contain more vegetable matter, the light or dark colored soils? Are the organic and inorganic particles distinct and separate, or do they adhere closely to one another? What is the source of the vegetable matter? The mineral matter?

Mineral base of soils.—Examine carefully these samples again and note the variation in size of the mineral particles. What name is given to the large mineral particles? Of what may these particles consist? What name is given to the fine, dustlike particles? Of what may these particles consist? What are the intermediate-sized grains called? Do you find particles of these sizes in greater or less abundance in all samples examined?

Mineral particles determined by sedimentation.—Place a tablespoonful of soil in a long pickle bottle and fill the bottle up to the neck with water; add a few drops of ammonia; shake well for at least three minutes. Set down the bottle and observe the settling of soil particles. The material which settles to the bottom during the first few seconds is coarse sand or gravel. The material which continues to settle more slowly during the next few minutes is silt. The water is turbid after settling has apparently ceased because of the fine clay particles in suspension. Put aside the bottle and find how long some of the fine particles will stay in suspension.

FIELD STUDY.

Where practicable, field trips or excursions may be made for studying the rock formation of the community, noting relations between the prevailing rocks and the types of soil. It should also be noted whether the particular areas of soil visited are of residual or transported formation.

REVIEW QUESTIONS, LESSON I.

1. Of what two parts does soil largely consist? From what does each part originate?
2. Name some common rock-forming minerals. What are sedimentary rocks?
3. What is humus? Explain how it is produced in the soil.
4. What is a physical change? A chemical change? A biological change? Give examples of each.
5. What is an element? A compound? Give examples of each.

6. What are residual soils, and what kinds of residual soils are formed from sandstone, limestone, and granite?

7. What is loess, and how is it produced?

8. Why are alluvial soils often found to be very coarse in the subsoil?

9. What are the characteristics of glacial soils, and how are they related to the rocks from which they were derived?

LESSON II. THE SOIL AND PLANT GROWTH.

Under favorable conditions of sunshine and heat, aeration and moisture, plants grow from materials furnished to them from the air and from the soil. Since plant-food materials are constantly being removed from the soil in the growth and harvest of crops it is important to understand to what extent the different farm crops draw upon the soil for plant food, what amounts of these materials are contained in the different soils, and by what means the soil replenishes the essential food materials for the needs of crops.

What the air and the soil furnish to plants (Ref. Nos. 1, pp. 16–20, 31–34; 3, pp. 477–482).—The atmosphere is one of the sources from which plant food is derived. The air is made up almost entirely of gases, nearly four-fifths being nitrogen, about one-fifth oxygen, and only four one-hundredths of 1 per cent, or about 4 parts in 10,000, carbon dioxid. Oxygen is used directly by plants as by animals. The air passes into the leaves, where a small amount of oxygen is taken up and combines with other materials in the cells. Carbon-dioxid gas is a compound of the elements carbon and oxygen. (See p. 4). In sunlight the green leaves of plants decompose this gas, fixing the carbon and returning the oxygen to the air. The carbon thus used comprises about 50 per cent of the dry weight of plants. Nitrogen is not taken directly from the air by plants, although it is a most important plant food.

When a quantity of any green farm crop is cut and allowed to wilt and cure in the sun it loses a large part of its weight by the evaporation of the water which it contains. If the cured material is heated in an oven at 212° F., the temperature of boiling water, it again loses weight for a time from evaporation. What remains is called dry matter. If this be burned, the organic matter passes away as gases while the mineral matter remains as ash. The water from evaporation contains the elements hydrogen and oyxgen; the escaping gases include the elements carbon, hydrogen, oxygen, and nitrogen, and the ash contains compounds of the elements potassium, phosphorus, calcium, magnesium, iron, sulphur, chlorin, sodium, and silicon. All of these elements except carbon and a small quantity of oxygen were secured by the growing plants from the soil.

It has been found by chemical analysis that the 13 elements mentioned above are present in all growing crops, but they vary in

quantity with different crops and with the stage of development of the plants. In general, the mineral elements and the nitrogen make up only about 1½ per cent of the dry weight of plants, while the carbon, hydrogen, and oxygen comprise about 98½ per cent of the total dry weight. While silicon, sodium, and chlorin are present in growing crops, these elements do not appear to be indispensable to the successful growth of plants. Attempts to grow plants without any of the elements carbon, hydrogen, oxygen, nitrogen, potassium, phosphorus, calcium, magnesium, iron, or sulphur have resulted only in failure. These elements have been called, therefore, the 10 essential elements of plant food. Whenever all conditions favorable to the best growth have been furnished to plants, with the exception that some one essential element was supplied only to a limited extent, the plants have never developed beyond the point made possible by the element which was limited in supply. When this principle is applied to crop production, it means that no matter how favorable the water supply, the tilth, and other essentials for growth may be, the harvest will never exceed what is made possible by the element which relatively is least supplied to the crop from the soil. The element of plant food thus limiting growth is called the limiting factor in crop production. The elements commonly considered as limiting crop production are nitrogen, phosphorus, and potassium. The management of soils so as to build up the supply of these elements of plant food is specially treated in Lessons VI and VII.

How soil materials are utilized by plants (Ref. No. 3, pp. 404, 405, 412–418; or No. 10, pp. 166–174).—Soil materials must be dissolved in water before plants can absorb them. The plant-food elements of the soil go into solution in the form of compounds called salts. A salt results from a chemical reaction between an acid and a base. An acid is a substance which will turn blue litmus paper red, while a base is one which will neutralize an acid and will turn red litmus paper blue. Vinegar contains an acid, while slaked lime is a base. When muriatic acid is added to slaked lime they react and form calcium chlorid, which is a salt. Calcium phosphate, potassium sulphate, and sodium nitrate are examples of salts which serve as sources of plant food. While these and all other salts must be dissolved before they can be utilized by plants, it is not necessary or even desirable that large quantities of plant food be in solution in the soil at any one time. Plant-food substances in solution or in condition to become so from the action of natural agencies are called available; those not in condition to become soluble for plant use are said to be unavailable.

Plants during growth absorb the soil solution through many small projections called root hairs. These root hairs constantly develop anew near the ends of protruding rootlets and keep in close contact with soil grains and immersed in the water film surrounding soil

grains. Root absorption of liquids takes place by a physical action called osmosis. If a bladder be filled with a solution like the white of an egg, the opening tightly tied with string, and the bladder put in a dish of salt dissolved in water, there is set up a movement of the salt solution through the walls of the bladder to the inside which soon distends the bladder to a considerable extent. The movement of liquid in this case is mainly inward, as colloidal solutions like the white of an egg pass but slowly through porous membranes. This movement will continue until the tension force from the stretch of the bladder walls equals the force which causes the water to move inward. The cause of the movement of the water through the bladder is called osmotic pressure. The illustration helps one to understand the movement of soil solution into the roots of growing plants. The walls of the cells composing the roots, like a bladder, are permeable to dissolved salts only, and the dilute salt solutions of the soil pass by osmosis through the cell walls into the denser solutions of the cell sap. When all the root cells become sufficiently turgid (distended) the plant-food solution is forced into the minute vessels and channels of the stem structure and upward to be utilized for growth.

Three conditions are necessary for the osmotic absorption of water by plant roots. These are: (1) A favorable temperature of the surrounding soil; (2) a supply of fresh air; and (3) a suitable quantity of water. Some plants are able to absorb water at temperatures as low as the freezing point, but this is not common. It has often been observed that the growth of potted plants is hindered by lowering the temperature of the soil by the use of cold water. A proper supply of water in the soil is indispensable for root absorption, but an excess of water shuts out the air from the soil and causes carbon dioxid poisoning and death of the root hairs, due to improper respiration or breathing in their cells. Soils are also made cold by much evaporation due to excess of water. The matter of air and water supply in soils will be considered at length in Lessons IV and V.

How elements of soil and air function in plants (Ref. No. 1, p. 37).—By supplying varying quantities of available mineral plant foods to growing plants with a suitable supply of moisture in the soil some conclusions have been reached concerning the functions of the essential elements. When a liberal supply of materials giving up nitrogen has been used, plants have produced rank, green foliage, often to the detriment of seed production. Therefore, when leaves and stems furnish the food part of plants, as with cabbage and celery, the soil growing these crops should be well supplied with available nitrogen. Seeds and grain contain relatively large quantities of the element phosphorus in combination. A good supply of available phosphorus-bearing materials hastens the maturing of plants and is particularly essential in the seed and grain crops.

Phosphorus also seems to bear an intimate relation to the development of plant cells. Potassium and calcium are closely allied with stem and root structure. A liberal available supply of these elements favors stiff, strong stems in grain and other crops. Potassium is also essential in starch formation. A good supply of available potassium in soils is needed, therefore, for root crops. Sulphur has an important function in cell structure. Iron is necessary in the forming of chlorophyll grains which give the green coloring to leaves and which, in the presence of sunshine, aid in the manufacture of starch in the leaves, largely from carbon dioxid and water. Carbon, together with water, composes a large percentage of plant structure and is the basis of all organic substance. Oxygen not in combination with other elements enters the plant and causes the breaking down, or oxidation, of other materials in the plant.

Soil materials removed by crops (Ref. No. 3, pp. 418–420).—In nature, as plants mature and decay, the soil materials used in plant growth are largely returned to the soil. The loss to the soil of inorganic or mineral substances by leaching and erosion is usually counterbalanced by the natural agencies of disintegration, while the organic or vegetable decomposition enriches the soil in nitrogen and returns the mineral substances again to the soil. Mineral compounds from vegetable decay, it should also be noted, become more readily available in the soil than do the minerals from rocks. Under ordinary farm practice, on the other hand, soil materials are removed in crops, waste occurs in connection with the management of manures, straw, and plant residues, and the soil often leaches and erodes very readily. All of these things deplete the fertility of the soil. The plant-food elements removed by crops vary with the yield, the crop grown, and the available materials in the soil. A reliable table showing the average quantity of nitrogen, phosphorus, and potassium removed from the soil by crops is found in reference No. 5, page 154.

Plant-food materials contained in soils (Ref. No. 5, pp. 58–60).—The amounts of the essential plant-food elements in soils are extremely variable. Since the nitrogen in soils comes almost entirely from vegetable decay, the supply of this important element depends upon the plant materials returned to the soil and the activity of the agencies of decomposition. The total supply of the mineral elements present in the soil, as stated in Lesson I, depends largely upon the original rocks from which the soil was formed. The quantity of materials available for plant growth, it must be understood, depends upon good soil management as well as upon the type of soil formation. Hopkins says:

> We can assume for a rough estimation that the equivalent of 2 per cent of the nitrogen, 1 per cent of the phosphorus, and one-fourth of 1 per cent of the total potassium contained in the surface soil can be made available during one season by

practical methods of farming. Of course, the percentage that can be made available will vary very much with different seasons, with different soils, and for different crops; and yet with normal soils and seasons and for ordinary crops the above percentages represent roughly about the proportion that is liberated from our common soils of the elements that limit the yield of the crop.

The meaning and value of chemical soil analysis.—Chemical analysis of soil is a means of helping to determine how areas of soil which are unproductive should be managed. A few things should be understood with regard to soil analysis: (1) It is highly important that the surface and subsurface soil samples be representative of the area examined. To this end it is advisable to get directions from the analyst before taking the samples of soil to be analyzed. (2) The chemical analysis of a sample of soil will probably not detect a bad physical condition which may be an important factor of its nonproductiveness. For example, poor drainage of a soil may not be evident from its chemical analysis. (3) A soil may be dead, so to speak, due to microbiological inactivity, or other causes. The regular process of soil analysis probably would not detect this condition. (4) Chemical soil analysis does give the amounts of nitrogen, phosphorus, and potassium in the samples of soil analyzed, and if the samples are representative the total quantities of these essential elements of plant food per acre to a stated depth can be quite accurately estimated. The supplies of these elements available for plant growth may also be indicated by the analysis, but the reliability of the methods used in determining availability is still a matter under discussion by soil chemists. It is safe to say that chemical soil analyses often indicate what is the limiting factor in crop production in the soil. (5) In soil analysis a test is made for acidity, and if acid is found this is stated in terms of the amount of lime necessary to correct the condition, and from this the application most practical for the cropping system in use may be estimated.

The relation between the terms nitrogen, phosphorus, and potassium, and the corresponding terms ammonia, phosphoric acid, and potash, commonly used by soil analysts, will be explained in subsequent lessons.

The possibility of exhaustion of soil nutrients (Ref. No. 3, p. 419).—It is a matter of common knowledge that the cultivated soils of the United States, under the ordinary farm practices, frequently become less and less productive. There are various causes for this decline in productiveness. The removal of plant-food materials in cropping, which has already been referred to, is one of these. The leaching of soluble compounds into the drainage water of soils is likewise a source of considerable loss. It has been found in general that soils have greater retentive power for compounds containing phosphorus and potassium than for compounds containing nitrogen. Sodium

nitrate, a common source of nitrogen, is readily leached from the soil. Very little loss occurs from the leaching of phosphorus compounds. The amount of leaching also varies considerably with the type of soil. Soluble materials are leached more readily from sandy soils, for example, than from clays. Erosion is another cause of much loss of fertility from soils. Leaching and erosion can both be avoided to a large extent by keeping the soil covered with plant growth.

There are several ways and means by which plant-food materials are replenished in the soil The removal by different agencies of surface-soil materials subjects the subsurface to increased action from the agencies of disintegration and decomposition which set free plant food. Then the dissolving action of water in the soil is constantly increasing the availability of the mineral nutrients. The return of organic matter in the form of manures, straw, and plant residues from crops and weeds is doubtless the best means at the command of the average farmer for keeping up the productiveness of his soil. Various substances in the form of commercial fertilizers are now much used, the quantity and nature of these materials depending upon the type of soil, the crops grown, and the judgment of the user.

EXERCISES, LESSON II.

Materials needed.—Balance; porcelain dishes; sodium hydroxid; red and blue litmus paper; muriatic acid; burnt lime; covered fruit jar; glass tubing; one-holed stoppers; rubber tubing; limestone; marble slab; some small boxes; sandy soil and a few kernels of corn; sealing wax; large-mouthed pickle bottles; and eggs (to be furnished by the class).

Composition of plants.—Take a growing plant and weigh it. Record the weight. Cut up and put pieces into a porcelain dish. Heat very gradually, causing the plant to wilt and dry out, but do not apply enough heat to cause charring or burning. While the drying is being done, hold a clean, dry glass plate over the containing dish. Remove glass at times and note from its appearance what is being expelled from the plant. After the plant is thoroughly dried, cool and weigh again. Record the weight. What percentage of the total weight passed off as moisture? Now burn the dried substance until only ash remains. Weigh again. Record the weight and figure the percentage of ash. The ash contains the mineral materials taken from the soil. The part consumed by burning represents what was formed from the carbon dioxid of the air and the water and nitrogen from the soil.

Formation of a salt.—Dissolve a piece of sodium hydroxid about the size of two peas in a *small quantity* of water. Dip the tips of forefinger and thumb into the solution and rub together. Note the feeling, then wash finger and thumb. Put about one-fourth teaspoonful of this solution into a separate dish (keeping remainder) and add about 5 teaspoonfuls of water. Dip finger into this solution and touch to the tongue. Note taste, then spit out. Put small piece of red litmus paper into this weak solution. What happens? Sodium hydroxid is a base. After noting all its properties, discard this *weak* solution.

(a) Put about 10 teaspoonfuls of water into a dish. Add *not over* 5 drops of muriatic acid and stir. Touch tip of finger to solution and taste, but *do not swallow*. After

noting taste, put a small piece of blue litmus paper into the solution. What happens? After noting properties of the acid, discard this solution.

(b) Now take the *original strong* solution of the sodium hydroxid and very slowly add muriatic acid, *drop by drop*. Place piece of blue litmus paper in the solution, keep stirring while slowly dropping in the acid, and stop adding acid *the instant* that the blue litmus paper turns red. Now pour the solution into a porcelain dish and boil until all the liquid has evaporated and the remaining substance is completely dry. Taste the residue. What is it? It was formed from a chemical reaction between an acid and a base.

Carbon dioxid of carbonic-acid gas.—Put a piece of burnt lime one-half the size of your fist into a pint fruit jar. Add water to slake the lime. Now add more water until can is nearly full, put on cover, shake thoroughly, then set away to settle. (One can of the liquid will probably suffice for the use of the class.) Put a glass tube through a one-holed stopper. (*Be careful* not to break the tube and cut the hands.) Fit a piece of rubber tubing over the end of the glass tube. Put a small piece of limestone into a bottle in which the stopper containing the glass tubing fits. Pour a little of the prepared limewater into one glass dish, or bottle, and a little water into another. Dilute not over one-half teaspoonful of muriatic acid by adding about 4 or 5 teaspoonfuls of water. Have the bottle containing limestone, the bottle containing limewater, and the bottle containing water all in readiness, then pour the dilute acid upon the limestone and quickly insert stopper containing glass tube. Put end of rubber tube into bottle containing limewater so that end of tube is below the surface. After the gas has passed into the limewater for a little time, remove the rubber tube and place it under the water in the other glass dish or bottle. The gas escaping from the bottle containing limestone is carbon dioxid. What effect does it have upon limewater? Put a small piece of blue litmus paper into the water through which the carbon dioxid has been passing for some time. What happens? Do you see why the gas is sometimes called carbonic-acid gas? Wash one of your glass dishes or test tubes thoroughly, then add another small quantity of limewater. Use a glass or rubber tubing and blow your breath through the limewater. What does your breath contain? Pour another small portion of limewater into a clean glass and let it set for some hours, or even days, in a place not dusty. What gas is shown by this experiment to be present in the air? The result can be shown much more quickly by using a bicycle pump and forcing air through the limewater.

Root hairs and the action of roots.—Place a square piece of polished marble slab at the bottom of a box about 4 or 5 inches deep, with the other dimensions equal to that of the slab. Place the polished surface up and fill the box with moist soil of a sandy nature. Plant a few kernels of corn in this soil. Put in a warm place and keep the soil moist. When the plants have grown at least 6 inches high, remove them very carefully. Note how the rootlets cling to the soil grains. Now clean the rootlets carefully with water and examine near the ends with the magnifying glass for root hairs. Remove the soil from the box and note the effect of the roots on the polished marble.

Osmosis.—Using sealing wax and a piece of glass tubing about 4 or 5 inches long; seal the tubing on the small end of an egg. Very carefully break and remove the shell, or outer covering, from a small portion of the other end of the egg. Fill a wide-mouthed pickle bottle with a strong solution of common salt and set the egg, tube upward, in the opening of the bottle. Now run a hatpin down the glass tubing and carefully break through both coverings of the end of the egg. Keep the bottle full of water and leave the egg set up in this way for several hours. What results? Stick the hatpin into the solution within the egg and taste. Do you now begin to understand how plants get dissolved mineral foods from the soil?

REVIEW QUESTIONS, LESSON II.

1. What chemical elements are essential to the growth of plants? In what condition are they utilized by plants?
2. What is a salt? Give example. Name some properties of acids and of bases which you have discovered. Give examples of acids, bases, and salts.
3. Tell what you understand by the limiting factor in crop production.
4. What are root hairs? Describe the process by which plants absorb materials from the soil.
5. Is it possible that plants might not be able to get enough plant-food material for their growth, even though the soil may contain sufficient quantities of it? Explain.
6. Mention a special function of potassium in plants; of phosphorus; of nitrogen.
7. How much nitrogen, phosphorus, and potassium are taken from the soil in removing a 100-bushel crop of corn? A 50-bushel crop of wheat? Three hundred bushels of potatoes? Six hundred bushels of apples? Four hundred pounds of butter? (See Table 23, Ref. No. 5, p. 154.)
8. Of what value is chemical soil analysis to the farmer? Discuss.
9. Give the means of removing and the means of replenishing plant-food materials in soils.
10. What is adsorption?

LESSON III. PHYSICAL PROPERTIES OF SOILS.

In farm practice the term "soil" is somewhat loosely used to include the furrow slice. It is commonly about 6 to 8 inches in depth, comparatively friable and porous, and in humid climates is darker and contains more organic matter than the part beneath, called the subsoil. These two parts are better designated by the terms surface soil and subsurface soil, both parts being comprehended in the general term "soil," which usually includes a layer of about 4 feet, or the depth to which the roots of farm crops commonly extend. In connection with tillage, soils are also spoken of as being heavy or light, depending upon whether they are hard or easy to work. Clay soils are hard to till, due to their fineness of particles and their stickiness. Sandy soils till easily, but are coarse grained and really heavier than the clays. All soils are mixtures of different-sized particles. The size of the particles determines the *texture* of a soil. *Structure* has to do with the arrangement of the particles of soil and is independent of their size. When the structure of soil particles is such as to be highly favorable to the growth of crops the soil is said to be in good *tilth*.

TEXTURE.

(Ref. No. 2, pp. 70–76, or No. 3, pp. 84–86, 97, and 102.)

Mechanical analysis.—To study texture the inorganic soil particles are separated into a number of grades according to size. This separation is called mechanical analysis. Fine wire sieves, carefully constructed, are employed for separating the coarser sands into different grades, and bolting cloth, such as is used in flour mills,

is used for separating the finest sands. To separate the still finer particles constituting silts and the clays it is necessary to shake the remaining portion of the soil thoroughly in water and then at different periods of time to draw off that which remained suspended during the previous period, allowing it to stand in another vessel for a longer time. By using these methods any number of different grades may be established. As a rule, however, but seven grades are separated. These have the following names and diameters expressed in millimeters and inches.

TABLE I.—*Grades and size of soil particles.*

Grade of soil.	Millimeters.	Inches.	Grade of soil.	Millimeters.	Inches.
Fine gravel	3 to 1	0.12 to 0.04	Very fine sand	0.10 to 0.05	0.004 to 0.002
Coarse sand	1 to .5	.04 to .02	Silt	.05 to .005	.002 to .0002
Medium sand	.5 to .25	.02 to .01	Clay, all particles less		
Fine sand	.25 to .1	.01 to .004	than	.005	.0002 and less.

The measurement of the diameter of these particles is made by means of a microscope.

Mechanical composition of various soils.—All soils contain some particles of each of the seven grades as previously given, but the proportion varies greatly. Heavy clay soils are largely made up of silt and clay particles with small quantities of the different-sized sands, while sandy soils are made up of relatively large quantities of the various grades of sand and correspondingly smaller quantities of silt and clay. It is therefore desirable to subdivide soils on the basis of the relative proportions of the different-sized grains. Soil investigators recognize on this basis coarse sand, sandy loam, fine sandy loam, loam, silt loam, clay loam, and clay.

These different classes of soils have the average mechanical composition or texture shown in Table II.

TABLE II.—*Average texture of important classes of soils.*

Class of soil.	Mechanical analysis giving average percentage of soil separated in each class.						
	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
Coarse sand	5	15	25	30	10	10	5
Sandy loam	5	10	10	25	15	20	15
Fine sandy loam	1	4	5	20	25	30	15
Loam	1	3	4	15	20	40	17
Silt loam	1	1	2	6	10	60	20
Clay loam	.....	1	2	5	15	42	35
Clay soil	.....	1	2	5	12	30	50

Quantity of surface exposed in soils.—The area of the total surface of the particles in a soil of fine texture is much larger than in one of coarse texture. The principle is illustrated by considering the effect

of dividing a block of wood 1 foot on each edge by sawing it through in the middle in the three directions. This will produce eight cubes 6 inches on each edge. The large cube will contain 6 square feet of surface; each of the smaller cubes will measure 6 inches, or one-half of a foot, on each edge and will contain one-fourth of a square foot on each surface. This multiplied by 6, the number of surfaces on a cube, then by 8, the number of small cubes, gives 12 square feet of surface. The area is therefore doubled by the division. The same division of each of these smaller cubes would again double the area, and so on. In the same way the division of a grain of sand into eight smaller particles having one-half the original diameter would multiply the entire surface exposed by 2. A cubic foot of coarse, sandy soil has about 40,000 square feet of surface, or nearly 1 acre. A cubic foot of sandy loam has about 65,000 square feet of surface, a cubic foot of clay loam nearly 105,000 square feet, and a heavy clay about 200,000 square feet, or nearly 5 acres. It should be noted, however, that under certain conditions the particles in soils of fine texture tend to flocculate or collect in small aggregates (see p. 20), thus reducing the effective area of exposed surface.

Relation of effective soil surface to fertility.—That the qualities of soils are largely influenced by the size of the soil grains is due to the fact that many of these qualities actually depend on the area of the total effective surface of all the soil grains in the mass of soil that the roots of plants occupy. The water held by the soil after draining is in the form of fine films surrounding the soil grains, and therefore the quantity depends on the extent of surface of the soil grains. Chemical and microbiological processes forming available plant food also take place on the surface of the soil grains. The finer the particles of any soil the greater is the relative quantity of available plant-food materials carried in the soil solutions. The total feeding area of plant roots is therefore increased as the size of the particles composing the soil is decreased.

STRUCTURE.

(Ref. Nos. 3, pp. 115–116; 184–197; 10, pp. 99–101.)

Plasticity and granulation.—The particles of a soil when wet have a tendency to stick together and to adhere to other objects with which they come in contact. This property of stickiness or ability to be molded is called plasticity. Coarse-textured soils show this property only to a very small degree. In soil-management studies, therefore, plasticity need be considered only in connection with the fine-textured soils, especially the clays. The plasticity of soil is due principally to the size and arrangement of the soil particles, the water present in the soil, and the materials contained in the soil solu-

tions. If clay soil is tilled when wet, its smaller particles seem to become more closely fitted into the spaces of the larger particles, and in this very plastic condition the soil is said to be *puddled.*

As wet soils dry out the water films surrounding the particles become thinner, which causes a contraction of the soil mass. This contraction causes separations between particles having least cohesion, which results in irregular cracking and the formation of soil masses of various sizes. Highly plastic clay soils which have become puddled form into large masses upon drying, and when tilled break up into clods. On the other hand, when rightly managed, clay soils upon drying form into small, irregular masses, which by tilling form a crumblike structure. This property is called *granulation.* The granulation of soils has a very important influence on the growth of crops, since it permits the excess of water to drain off more readily than would be the case if all the soil grains were as closely arranged as possible, and it offers the roots of the plants an opportunity to penetrate the soil much more readily than they could otherwise do. It also gives the air better access to the growing roots and to the microorganisms causing changes in the soil.

Agencies producing granulation.—The principal agencies which affect granulation in soils are: (1) Good drainage. Where land is well drained any excess of water quickly passes away instead of saturating the soil and thus inducing puddling and the formation of solutions which hinder granulation. (2) The use of lime. The addition of lime to clay soils causes a flocculation, or gathering into aggregates of materials suspended in the soil solutions, and thereby reduces plasticity and promotes granulation. (3) Insects and plant roots. The borings of insects and earthworms, and the penetration of plant roots far into the subsurface soil, deepen the zone of granulation. (4) Decaying vegetable matter in the soil. It is believed that the humus in the soil becomes distributed over the surfaces of soil grains and through the solutions of the soil, reducing its plasticity and permitting better granulation. At any rate, it is a practical fact of common farm experience that plowing manure, straw, and plant residues deeply into the soil produces a loosening, granulating effect which makes tillage easier and adds to productiveness. (5) The growth of grasses. The fine, fibrous roots of grasses, completely permeating the openings of the surface soil, attach themselves thoroughly to the soil particles and gradually develop a condition of granulation. The good tilling properties of land which has been in grass for several years are well known. (6) Tillage operations. Soil must be tilled at the right time and with the right implements to secure the best granulation.

Pore space in soils (Ref. Nos. 10, pp. 101, 102; 3, pp. 108, 109).—Pore space in soils may be thought of as the space not occupied by the

solid soil particles and the moisture film surrounding these particles. It is the space in well-drained soils which is open to the circulation of air and other gases and to the growth of plant roots. The total pore space in any soil depends less upon the size of soil particles than upon the arrangement of these particles. From the standpoint of pore space the granules in soil are similar to single soil grains. The pore space in sandy soils under ordinary field conditions is about 40 per cent of the total. In clay loams the granulation is commonly such that 55 per cent of the total volume of the soil is pore space, only 35 per cent being occupied by solid matter; while in fertile heavy clays granulation may be present to such an extent that 65 per cent of the total volume is pore space. Ample pore space in soil to a depth of 4 feet or more is very essential to a thorough distribution of plant roots, and a free circulation of air in the soil is indispensable to the growth of farm plants.

Circulation of air in the soil.—Some of the principal causes of the circulation of air in soils are: (1) Water movements in the soil. Any movement of water through the soil has an effect upon the circulation of the soil air. A good example of this is seen in underground drainage. Following rains, or accompanying irrigation in arid lands, as the water passes downward through the soil into the drains, the atmospheric pressure forces the air into the pore spaces opened by the water passing out. (2) Changes in barometric pressure. Variations in the pressure of the atmosphere, indicated by the barometer, produce currents of air, or winds, which pass over the earth's surface. These causes of surface movements of air also affect subsurface movements of soil air, but to a lesser degree. (3) Changes in temperature, due to day and night. After sunset the atmosphere cools more rapidly than the earth's surface. The warmer air of the soil, being lighter, moves upward through the pore spaces and into the atmosphere, while an equal volume of cooler air above the surface moves downward into the soil to take its place. (4) Diffusion. It is a physical law that when two gases are in contact they always mix, or diffuse. Carbon dioxid given off in the soil from the roots of plants and from vegetable decay, together with other soil gases, gradually diffuses in the soil air and thereby helps to produce a certain kind of circulation.

Among the causes influencing pore space and soil-air circulation those most under control in soil management are drainage and granulation. If soils are filled with water there can be no circulation of air therein. On the other hand, if clay soils are so managed as to become puddled and baked, the lack of pore space and granulation will result in poor circulation of air through them and thus prevent the successful growth of plants.

TILTH.

(Ref. No. 2, pp. 277–283.)

Soil management to produce good tilth.—Ample pore space and thorough granulation in a soil are two of the most important factors of good tilth. It is impossible in a brief treatise of this kind to formulate rules for tillage covering the use of all farm implements, for all farm crops, grown upon all types of soil. But a thorough knowledge of the principles involved and the ends to be attained is of greater value in farm practice than any set of rules. It is only by experience, together with a mastery of the principles of soil management, that the best tilth will be secured and the best results in farming produced. This is especially true of the different clay soils, many of which are fertile, but all of which require intelligent management.

EXERCISES, LESSON III.

Materials needed.—One-pound baking-powder cans; a balance or scales, 2 quarts each of dry sand, clay, silt loam, clay loam, sandy loam, loam; several 1-inch wooden cubes; any simple apparatus to measure cubic inches of water; set of soil sieves; pie tins, or saucers.

SOIL TEXTURE.

Heavy versus light soils.—Take two 1-pound baking-powder cans of equal weight and fill one level full with air-dried sand. Fill the other with finely divided air-dried clay or silt loam. Compare the weights of these two volumes of soil. Which does the farmer usually consider as light soil? Why? Why is the other commonly called a heavy soil? To which soil may the term fine textured be applied? Describe the texture of the light soil.

Soil classes based on size of soil grain (Ref. No. 3, p. 77).—Obtain dry samples of sand, clay, silt loam, sandy loam, clay loam, and loam. Examine each class carefully with a hand lens and note the following characteristics: Comparative size of soil particles; the feeling between the fingers when wet, whether gritty, sticky, or velvety; kind of soil particles based on texture.

(To THE LEADER.—A tablespoonful of each sample of soil may be placed in separate small dishes and labeled to enable the members of the class to work alone or in pairs. After the members have become familiar with each soil class, unknowns may be passed out for identification.)

Mechanical analysis.—Take about half of a pound baking-powder can of two or three different kinds of dry soil. Weigh each sample separately and record. Take one kind of soil and pour upon the coarsest soil sieve. Shake until no more of the material passes the sieve. Retain the part passing through. Weigh the part retained by the sieve and record the weight. Take the part passing through the sieve, repeating the process as above with the next finer sieves in order and recording the weights, until all the sieves have been used. Compare percentage of separates with table on page 18, and try to determine the correct names for classes of soils used.

Texture and film water (Ref. No. 2, pp. 157, 158).—(a) Take eight 1-inch cubes and build them up into a 2-inch cube. How many square inches of surface does this 2-inch cube have? Determine the total number of square inches of surface on all the smaller cubes.

Cutting a cube in three directions increases the number of cubes how many times? How many times does it increase the surface area?

(b) Let the original 2-inch cube represent a soil grain of a coarse-textured soil. Cut it in three directions, and cut each resulting cube again in three directions. Into how many cubical particles is the original soil grain now divided? The total surface area of these particles is now how many times that of the original soil grain?

A soil made up of these resulting particles is how much finer textured than soil made up of particles like the original soil grain? Which soil will hold more film water? Why?

Texture and pore space.—Secure two 1-pound baking-powder cans and make them water-tight by use of a little paraffin. Fill one within half an inch of the top with dry sand, and the other with dry clay loam and silt loam. Measure carefully the cubic inches of water required to saturate the soil in each can. Apply the water to one edge of the can only as fast as it is absorbed by the soil. This will allow the air in the soil pores, or spaces, to escape. Determine the number of cubic inches of soil in each can ($3\frac{1}{7}$ times radius squared times height of soil column equals volume) and compare each volume of soil with the volume of water required for saturation.

What percentage of the volume of sand is water?

Where is this water in the soil? Draw a diagram showing the relation of the sand grains to the water. What, then, is the approximate percentage of pore space in the sand? In the clay or silt loam? Explain fully why clay or silt loam is more porous than sand. When is a soil said to be saturated? What is the relation between the porosity of a soil and its texture? Between porosity and weight of dry soil?

Plasticity.—Place small quantities of a clay soil and some other class of soil upon two different pie tins or saucers. Add water slowly to each and continue to stir until the samples can be molded like dough. Which soil shows the greatest degree of plasticity? Add water and mix each sample until the soils have become puddled. Set aside to dry. What happens to the two samples when entirely air dried?

Granulation.—Put a small sample of dry clay soil upon a dish and add water without stirring so slowly that the soil absorbs it as fast as added. Do not add water enough to saturate the soil, only add what would be held by a well-drained soil. Set the soil aside to dry and try to stir at just the time when best granulation can be effected. How does the structure of this soil now compare with the dried-clay sample that was puddled?

Field trips.—If possible, field trips should be made to study soil classes. With a spade dig down through the surface soil and partly into the subsurface. Make a smooth, perpendicular edge. Now note line between surface and subsurface and measure the exact depth of the surface soil. Observations as to differences of color, texture, and structure should also be made. What has caused these variations?

REVIEW QUESTIONS, LESSON III.

1. What is meant by texture of soils? By structure?
2. How do you distinguish between heavy and light soils?
3. By what process is the texture of the soil determined?
4. Compare the sand, silt, and clay content of a fine sandy loam with that of a clay soil.
5. Mention some ways in which the fertility of a soil is influenced by its texture.
6. Explain fully the influence of the area of surface of the soil grains on the water-holding capacity of soils.
7. What is meant by soil granulation? Soil tilth?
8. Mention several agencies which develop granulation in soil.
9. How is puddling of soils produced?
10. What is meant by pore space in soils? Draw diagram to illustrate.
11. About what fraction of clay loam soils under the ordinary field conditions is pore space?

12. Give some influences which cause a circulation of air in soils.
13. Why is air circulation in soil important?
14. Discuss the different factors which have to do with good tilth.

LESSON IV. THE WATER SUPPLY OF THE SOIL.

The soil is a reservoir which stores a part of the water supplied to it by rain and irrigation, giving it up again to meet the needs of growing plants.

Water-holding capacity of soils (Ref. Nos. 2, pp. 157–162; or 3, pp. 210–218; 10, pp. 119–122).—If the surface soil of a field is thoroughly saturated with water for some time, most farm-crop plants stop growing, because the small amount of oxygen dissolved in the water will not suffice for the needs of the plants and further supplies can not penetrate the saturated soil. If land with a porous subsurface or an underdrainage system be examined after a thorough soaking with rain, it will be found that the water remaining is held in the form of films surrounding the individual soil grains and the smaller clusters of soil particles. The excess of water which has drained away under these conditions is called drainage or gravitational water. (Ref. No. 10, pp. 104, 105.) That which remains is called capillary or film water. (Ref. No. 10, p. 106.)

Since capillary water exists as a film surrounding the soil grains and therefore depends on the area of these particles, fine-textured soils can hold more water than coarse-textured soils. Moreover, this capillary water in the soil not only forms films around the soil grains, but these films are continuous from the surface downward in such a way that the moisture in the subsurface soil forms a weight on the films above, just as the lower links in a chain hanging by one end produce the weight supported by the upper links. The result of this is that the films near the surface in the soil are stretched by the capillary moisture below, so that a soil layer which is a number of feet above saturated soil can hold less capillary water than a layer only a few inches above saturated soil. The amount of capillary moisture held by the soil after a heavy rain depends, therefore, not only on the texture of the soil, but on the distance to the saturated subsurface soil on the ground-water table. The thickness of these films also varies with the temperature of the water. Films of warm water are drawn out considerably thinner than those of cold water. As a result of this principle, as soils get warmer during the summer, the quantity of capillary water diminishes.

Organic matter and water-holding capacity (Ref. No. 3, p. 218).—Vegetable matter in the soil in various stages of decomposition has a strong power to absorb and hold water. In a well-advanced stage of decay, as with muck and humus, organic matter can hold several times its own weight of water and very much more than the mineral

part of the soil can hold. In clay soils humus also has a considerable indirect influence on water-holding capacity through its power to affect granulation.

The total quantity of water held by different soils when saturated has been found to vary from about 40 per cent of their dry weight in coarse sand to about 55 per cent in well-granulated clay, and up to over 300 per cent, or three times its dry weight, in muck. The quantity of capillary water which these same soils have been found to hold varies from about one-fourth of the amount held upon saturation in coarse sand to over one-half in well-granulated clay, and up to nearly the total amount in muck. The larger capillary capacity of the muck is due largely to its high absorptive power. (See tables, Ref. No. 3, pp. 154–162.)

Water available to plants (Ref. No. 3, pp. 200–202).—Crops growing in soil are unable to take all the water which it holds. If soil in which plants have died for lack of water is thoroughly dried in an oven it will be found that there is expelled a small quantity of moisture which the plants were unable to secure. Coarse-textured or sandy soils retain very much less of such water than do the fine-textured clay loams or clays. This is because the plants are able to withdraw the water only to a given thinness of water film around the soil grains, and the larger total exposed surface of the fine-textured soils causes them to retain the larger quantity of water. It is evident, therefore, that only a part of the capillary water can be considered as available for growing crops. When the ground-water level is 10 feet below the surface the upper 4 feet of a very sandy soil can hold available water equal to a layer of about 3 inches in depth, a sandy loam 4½ inches, a silt loam 6 inches, and a well-granulated clay soil 7½ inches.

Water required by growing crops (Ref. Nos. 1, pp. 12–16; 10, pp. 12–17).—It was stated in Lesson II that water is used by plants directly as a plant food, and further, that water dissolves mineral substances in the soil and carries them to all parts of growing plants, where the mineral elements are utilized so as to perform their special function. In fact, all movements of substances within the plant take place largely through the medium of water. The larger portion of the cell sap of growing plants is composed of water. An average of 80 per cent or more of the green weight of staple farm crops is water. When the water supply from the soil is insufficient, the plant cells become shrunken, causing wilting. The temperature of growing plants is also regulated to some degree by the transpiration of water in the form of vapor from the leaves and stems. The quantity of water transpired, that is, given off as vapor to the surrounding air by growing plants far exceeds the quantity directly utilized to form plant substance. Experiments have shown that for every pound of dry

matter stored in ordinary crops an average of about 350 pounds of water is taken from the soil. This amount varies widely under different conditions and with different crops. Vivian says, "There is no doubt that the proper condition of moisture is the most important single factor in determining the fertility of the land, and that more soils fail to produce good crops for lack of it than for any other cause."

Variations in water requirements.—There is no necessary relation between the rate of growth and the quantity of water transpired by the plant. When all conditions are favorable to rapid growth the quantity of water transpired for each pound of dry matter produced seems to be distinctly less than when an essential element of plant food is lacking, or when disease attacks the plant, or any other cause exists which lessens the rate of growth. Moreover, there is a very marked influence of climatic conditions, especially temperature and humidity of the atmosphere, on the quantity of water which plants require. Most staple crops growing in the dry, clear atmosphere of Utah, for example, require from 50 to 100 per cent more water than in Wisconsin. But there also seems to be a marked difference among crops in respect to the relative quantity of water they require. Expressed by rainfall in inches, it has been found that in the eastern part of the United States and in Europe a crop of corn yielding 90 bushels per acre requires on the average 15 inches of water, one of oats yielding 75 bushels per acre requires 12 inches, 300 bushels of potatoes per acre, 6¼ inches, and 2 tons of clover hay, 9 inches. These figures include the water lost by evaporation from the surface immediately under the plant when careful tillage and mulching to prevent evaporation are practiced, as well as that transpired by the plant.

Depth to which roots extend for water (Ref. No. 10, pp. 86–93).—In climates which have frequent showers during the summer period, crops get most of their water comparatively near the surface and do not usually extend their roots for moisture more than 3 or 4 feet in depth. On the other hand, in regions in which there is a heavy winter rainfall and a long, dry summer, crops sown in the spring must go deeper and deeper for their moisture as summer advances and the rains cease. Some crops, especially alfalfa, are able to send their roots to great depths, often 20 feet or more. Under such conditions the water-holding capacity of the soil to great depths must be considered. In the Mississippi Valley, with considerable rainfall during the summer, one may be satisfied with a soil having a good water-holding capacity to a depth of 6 or 8 feet. On the Pacific coast and other parts of the country, where the rainfall comes all during one season, it is important that a fine-textured soil continue to a depth of 15 to 20 feet. This is particularly true for fruit trees.

Capillary rise of water (Ref. No. 4, pp. 30, 31).—Fortunately, crops are not entirely dependent on the moisture held in the layer of soil to

which their roots penetrate. After this has been partially dried out, as a result of the extraction of water by the growing crops, the water films are reduced somewhat in thickness and therefore have acquired greater tension and have the power of drawing up some of the moisture in the thicker films of the soil below. This capillary rise of water undoubtedly causes an important addition to the available supply. This movement of water varies greatly, however, in soils of different texture. It is of importance in coarse or sandy soils only when the ground-water level is within 10 or 12 feet of the surface, while in heavy clay soils it may come from considerably greater depths. The capillary movement is not rapid, but it is much faster in sandy than in clay soils. In the case of rapidly growing crops, especially on clay soils, in which the rate of capillary rise is slow, the water supply furnished in this way is altogether inadequate to maintain growth after the moisture in the surface soil has been reduced to the lower limits of good growing condition. It is, nevertheless, an important addition to the moisture already held in the soil.

Capillary rise of water in soils is illustrated by holding two glass tubes of very small but different-sized bores perpendicular, with the lower ends under the surface of water. In both tubes the water will rise above the surface level of the water in the containing vessel, but the column in the smaller tube will stand the higher. This rise of water in capillary tubes is due to two forces: (1) The attraction of the glass for water, which causes the water to creep up the tubes a little above the general level of the water surface within the tube; and (2) the tension, or stretch, which is on the surface of all liquids. If a dry needle is carefully placed upon a smooth surface of water, the needle will float, but can be seen to be causing a stretch of the liquid surface beneath it. This elastic tension of a liquid surface causes the surface within the tubes to tend to form a plane. The simultaneous action of these two forces noted will cause the water to rise within the tubes until the weight of the water therein equals the force of tension of the surface films. The column of water in the smaller tube, being the lighter, will rise to the higher level.

In soils, the openings between particles, or pore spaces, serve as capillary tubes, and the perpendicular rise of water behaves in accordance with the laws of capillarity. Fine-textured soils, therefore, have a higher rise of water from this cause than soils of coarse texture, although the rate of rise is much slower in the former. There are, however, other factors of practical importance affecting capillarity in soils which should be noted: (1) Some mineral salts in solution strengthen the surface tension of water and add somewhat to the rise of water in soils; (2) heat reduces the strength of the surface film of water and other liquids as well; and (3) some liquids, such as those from manures and decaying vegetable matter, have been found

to reduce the surface tension of soil water and so lessen to a slight extent the rise of water in the soil by capillarity.

Rainfall in relation to water requirements of crops.—According to a report from the United States Weather Bureau the normal annual precipitation from rain and snow in different parts of this country between 1870 and 1901 varied from 1 inch to 100 inches. The great agricultural area included in the central basin of the Mississippi River had a mean annual precipitation varying between 30 inches and 50 inches; the North Atlantic and Middle Atlantic States had from 40 to 50 inches; the South Atlantic and Gulf States from 50 to 60 inches; the Great Plains States from 15 to 30 inches; the Rocky Mountain States from 1 to 20 inches; while the annual precipitation of the Pacific States ranged from 10 inches in the extreme southwest to 100 inches in the extreme northwest. It has been stated under "Variation in water requirements," that the growth of 90 bushels of corn per acre requires approximately 15 inches of water; 75 bushels of oats, 12 inches; 300 bushels of potatoes, 6¼ inches; and 2 tons of clover hay, 9 inches. Comparing these figures with the normal annual precipitations of the principal agricultural areas, it will be seen that the moisture falling as rain or snow would in nearly every instance be sufficient to produce large yields of staple crops if it could all be held in the soil and utilized for plant growth. It will be recalled, however, that the different classes of soil can hold in the upper 4 feet only from 3 inches to 7½ inches of water available for plant growth at any one time. On the other hand, over all the agricultural areas of highest precipitation the fall of moisture is very unevenly distributed throughout the year, and the larger quantities do not fall during the growing season. Because of this, large quantities of water drain away from the land, making it necessary in nearly every farm area to adopt means to prevent the escape of moisture from the soil.

Prevention of evaporation (Ref. No. 6, pp. 108–119; or No. 10, pp. 147–164).—The most effective preventive of loss of capillary water from soil is a dry surface which retards the movement of moisture through it. Probably everyone has tried the old experiment of making a path for a little stream of water by wetting a finger and drawing it along a gently inclined board and has been astonished to see how irregular a path the water can be made to follow by this means. This is because the film of water supplied by the wet finger offers less resistance to the movement of the remainder of the water than does the surface of the dry wood. In the same way moisture in the subsoil can pass upward by capillary action much more readily when the soil is moist than after it has been dried. A surface layer a few inches in depth of thoroughly dry soil practically prohibits the further capillary rise of water to the surface. Water does, of course,

continue to evaporate at the upper portion of the layer containing moisture, but the surface layer of dry soil keeps the moist soil below somewhat cooler, so that loss by evaporation is greatly lessened. A dry, loose layer of soil or other material is called a mulch. The development of a soil mulch is by all means the cheapest and usually the most effective way of reducing the water loss by evaporation. The common farm method of developing a soil mulch is by cultivation, which also kills weeds and promotes the circulation of air in the soil.

The loss of water from surface evaporation, other conditions being equal, is greater in fine-textured than in coarse-textured soils; likewise, the firmer the soil surface, the greater is the loss. This explains an objection to leaving a rolled surface in preparing a seed bed or after planting. Experimental results from cultivation to depths of 1, 2, and 3 inches, respectively, and at intervals of one-half, one, and two weeks have shown, in general, that within these limits the deeper the mulch and the more frequent the cultivation, the greater are the quantities of soil moisture preserved. A general average from these same results shows that a soil mulch prevents the evaporation of about 3,500 pounds of water per day over each acre of land, which is about one-tenth of the quantity required during three months of the growing season to produce a 90-bushel crop of corn. While these results vary considerably with climate, soil, and season, yet they are significant in showing the means of retaining moisture in the soil by cultivation.

The depth of mulch which is desirable depends on circumstances. Under most conditions a mulch of 3 inches has at least three-fourths the efficiency of a mulch of 5 or 6 inches in depth, and in the case of such crops as corn, in which the roots are apt to come close to the surface, so that cultivation to a depth of 5 or 6 inches would cut off many of them, it is unwise to attempt to produce a mulch more than 3 or 4 inches in depth. In many cases the cultivation of the soil from 2 to 3 inches in depth is to be preferred. Deep cultivation is generally undesirable in the Mississippi Valley and the eastern part of the United States. Farther west, where the rainfall is 25 inches or less annually, and the roots of plants are forced to grow deeper, a greater depth of mulch is considered desirable, and it is a common practice to cultivate to a depth of 5 or 6 inches.

Dry farming (Ref. No. 10).—Dry farming is a term which has come to be applied to the practice of agriculture in the arid lands of the West and Northwest. Where irrigation is impracticable, and where the annual rainfall is so low that it is impossible to grow a crop each year, land is fallowed every other year by keeping up a thorough cultivation which prevents the growth of vegetation and

keeps up a protective mulch over the surface. This mulch and the destruction of weeds largely prevent the loss of moisture from the soil and it is held for use by the crop of the following year.

Other means used to control the water supply of the soil are irrigation and drainage.

EXERCISES, LESSON IV.

Materials required.—One small balance or scales; four 1-pound baking-powder cans; 4 quarts each of dry sand, dry muck or peat, dry clay or silt loam; one 2-quart pail; a small piece of cloth; two cups; two or three pie tins; two or three small shallow dishes (saucers); a small quantity of lump and powdered sugar; six fine sewing needles; two pieces of $\frac{3}{4}$ or 1 inch glass tubing 2 feet long; one-half bushel of moist loam or silt loam; two 2-gallon crocks.

Water-holding capacity of soils (See reference in lesson).—Turn four 1-pound baking-powder cans upside down and punch three holes in the bottom of each. Obtain the weight of each can. Fill can No. 1 with dry sand, can No. 2 with dry muck or peat, can No. 3 with dry clay or silt loam, and can No. 4 with a mixture of one part (by volume) of dry sand and one part of dry muck or peat. Determine the weight of dry soil in each can. Saturate all with water, let stand until no more water drips from them, then weigh again. Determine the percentage of capillary water retained by each kind of soil. Account for the variation in water-holding capacity of the several samples. How may the water-holding capacity of a sand be increased? Of a heavy clay? Which class of soil will give up its water the easier, sand or clay? Why? On which soil do crops suffer more for want of water during a drought?

Percolation of water through soils (Ref. Nos. 2, pp. 170–173; 4, p. 32).—Punch a half-inch hole through the side and near the bottom of a 2-quart tin pail. Cover the opening on the inside with thin cloth and fill the pail with sand. Put a stopper in the opening and saturate the soil with water, measuring the quantity of water used. When saturated, remove the stopper and catch and measure the water that runs out. When dripping ceases compare the quantity of water caught with that used to saturate the soil. What name may be given to the water retained by the soil?

Capillary rise of soil water.—Pour a cupful of dry sand on a pie tin in a conical pile. Pour about a third of a cupful of water into the tin (not on the sand pile) and observe results. What name is given to this phenomenon? Of what importance is it in agriculture? Is this the only direction in which film water moves in the soil? What determines the direction of movement? In what kind of soil will water rise the higher, sand or clay? Explain. Repeat this experiment, if possible, by using 2-foot glass tubes filled with dry sand and clay loam. Cover the lower end of each tube with cloth, tamp the soil carefully, and stand tubes in a tray. Pour about half an inch of water into the tray and observe results. Note carefully the rate of rise and the height to which the water will rise in each tube.

Resistance of dry soil particles to water films.—Fill a small dish with water; place a perfectly dry, fine needle carefully on the surface film of the water. The needle will float. Explain. Take a pinch of road dust and let it drop carefully into the water. What happens to the finest dry particles? Explain. Why do water drops roll off a dusty board like so many shot?

Conserving soil moisture (Ref. No. 3, p. 264).—Sprinkle as much powdered sugar on top of a lump (do not press down the powdered sugar) as it will hold, and place the lump in a pool of about 12 drops of water poured out on a smooth surface. What happens? Explain fully. Let the lump of sugar represent a portion of soil immediately underneath a thoroughly cultivated surface. What does the powdered sugar represent? Is this principle of moisture conservation practiced in connection with all farm crops? Repeat the experiment using dry caked and powdered clay.

Obtain about 16 quarts of moist soil, mix well, and fill one 2-gallon crock within half an inch of the top, leaving the surface smooth and compact. In filling this crock tamp the soil gently so as to bring the soil particles in close contact with each other. Fill another crock in a similar manner within an inch and a half of the top. Cover this surface, which should not be too compact, with an inch and a half of loose dry soil. Place both crocks exposed to sun and circulating air. Do not water. After a week or 10 days take off the dust mulch in crock No. 2 and compare the moisture content of the soil beneath with the soil 1½ inches beneath the surface of crock No. 1.

What precautions should be observed in frequent cultivation during a dry period? Is it possible to keep a heavy soil in good tillable condition if soil mulching is practiced? What should be done with the garden during dry seasons to conserve the water applied in the evenings? When should this be done? Why?

Field excursions.—Observations may be made concerning methods of cultivation, soil mulching, crop growth on low, wet lands, on gravelly knolls, etc.

REVIEW QUESTIONS, LESSON IV.

1. What is meant by water-holding capacity of a soil?
2. Distinguish between gravitational or drainage water and capillary water. Draw a diagram to illustrate how capillary water is held by the soil.
3. What is meant by the ground water table?
4. Explain the relation between texture and capillary water content of soils.
5. Why is the water-holding capacity of soils affected by the percentage of humus they contain?
6. Compare the quantity of water available for growing crops, a few days after heavy rains, in the depth of 4 feet of a silt loam and a very sandy soil.
7. Explain the cause of capillary rise of water in soils.
8. Explain fully the way in which evaporation of moisture from the soil may be lessened and state the principles underlying this method.
9. Why is it that a rainfall of 15 inches in the northern part of the United States is as effective for the growth of crops as one of 25 inches in the southern portion?
10. To what extent do you think that the moisture in the subsoil at a depth of 20 feet may be counted on for support in growing large crops? Discuss fully.

LESSON V. SOIL TEMPERATURE AND DRAINAGE.

SOIL TEMPERATURE.

(Ref. No. 2, pp. 218–238; or No. 3, pp. 289–294; 314–317; 325.)

It is a well-known fact that the soil must be comparatively warm before plants will grow. The limits of temperature for growth vary considerably for different farm crops, and there is some variation in the temperature necessary for the growth of any one crop in different latitudes. It has been found that, with other conditions favorable, staple crops will grow when the soil temperatures are as low as from 40° to 50° Fahrenheit, and as high as from 110° to 120°. The best growth ordinarily takes place at temperatures ranging from 65° to 70°. In the United States, especially in the northern half, the average soil temperatures for the growing season are considerably below these figures. Besides being necessary for the performance of the functions of growth in plants, certain temperatures are also essential in order that the chemical reactions and the microbiological activities furnishing available plant food may take place in the soil.

Factors influencing soil temperature.—The sun is the chief source of heat for the earth's surface. The sun's rays are conducted to the earth as light. These rays are transformed into heat and absorbed, or are largely reflected back into the atmosphere, depending upon the condition of the soil material which the rays reach. Dark soils transform and absorb as heat much more from the sun's rays than do light-colored soils. Besides the sun, an indirect source of a small amount of heat is the chemical and microbiological changes taking place in the soil. A chemical reaction usually produces heat, and microbiological activities frequently do.

The principal conditions affecting the temperature of the soil are: (1) Latitude. The farther north or south of the equator a land surface is the less direct are the sun's rays upon it and, other things being equal, the less will be the total heat absorbed in any given time. (2) Slope. A southern hillside will be warmer than the northern, because the sun's rays upon it are more direct. (3) Circulation of air above the soil. The varying temperature and humidity of the currents of air upon hillsides and in valleys have a considerable effect upon the temperature of the soil areas over which they pass. (4) Composition and texture of the soil. Both of these factors affect the conductivity of heat into the subsurface soil. Some rock materials are better conductors of heat than others. Again, air is a poor conductor of heat, and the greater the pore space in soil the less rapidly will heat be conducted through it. Fine-textured soils thus conduct heat less rapidly than coarse-textured soils of like composition. Clay soils warm up less quickly in spring than sandy soils which have less pore space. Peat soils formed in marshes are very open and spongelike, and this large air space causes heat to pass down into such soils with extreme slowness. Frost is often found in marshes several weeks after it has entirely disappeared in upland and more compact soils. (5) Water content of the soil. This has a very important influence upon the soil temperature. It takes nearly twice as much heat to raise water 1° in temperature as it does to raise the same weight of soil 1°. Then the evaporation of moisture from the surface of the soil uses up a great deal of heat and does much to keep the soil cold. It requires as much heat to evaporate a pound of water as would raise the temperature of a cubic foot of average soil over 10° Fahrenheit. (6) Color. Dark-colored soils, other conditions being equal, are warmer than light-colored.

There are at least four practical means by which the temperature of soil may be regulated: (1) By means of vegetable matter. A good supply of barnyard manure or green manure in the soil will have an appreciable effect in warming it. (2) By rolling. The heat conductivity

of soil can be much improved by rolling, especially when the surface is loose. By this means an additional amount of heat can be carried into the subsurface soil. At a depth of 3 inches rolling commonly warms the soil as much as 3°. If the surface soil is moist, however, the rolling should be followed at once by cultivation to prevent evaporation of moisture. (3) By use of a soil mulch. As has been stated above, the evaporation of moisture takes a great deal of heat from the soil. The soil mulch, by preventing evaporation, conserves much heat for the growth of crops. (4) By drainage. In well-drained soils the gravitational water is drawn off from beneath instead of evaporating from the surface. Soil that is tile drained is 5° to 10° warmer in the spring than it was before it was drained. The temperature of the soil in turn affects the temperature of the air in immediate contact with it, and frost often occurs on poorly drained soil at night where it does not form on well-drained soil.

DRAINAGE.

An excess of water prevents the entrance of the necessary air into the soil; it hinders the normal development of soil microorganisms; it leads to the puddling of clay soils and consequently produces poor tilth; it keeps the soil cold, especially in the spring; and, finally, it causes a leaching of plant-food substances from the soil.

Conditions where drainage is necessary (Ref. No. 8, pp. 14–16).—It is usually not difficult to detect the need of drainage. There are cases, however, when late in summer it is difficult to determine whether partial crop failure was caused by poor drainage earlier in the season or from the lack of necessary elements of plant food. Water should not stand on the surface of cultivated soils any longer than can be helped. Especially in the Northern States, where the growing season is short, it is desirable to have drainage in the spring as thorough as possible. Soil should not be saturated within 3 feet of the surface for most crops, though many grasses will make a very good growth on land which is saturated within 18 inches of the surface, or even nearer, for a portion of the growing season. Drainage is especially desirable in irregular fields where the drainage of wet portions will permit the laying out of a field of proper dimensions and also make it possible for the whole field to be tilled at one time. This not only increases the acreage of available land but greatly increases the efficiency with which operations of tillage and harvesting can be performed. Drainage in any case simply removes the gravitational water, and it is a mistake to think that good drainage is detrimental to crops, even in dry seasons.

It is customary to speak of surface and subsurface drainage, referring to the removal of surface or flood water in one case and to the withdrawal of the excess of water from the subsoil in the other.

Surface drainage (Ref. No. 8, pp. 7–9).—In the removal of surface water it is ordinarily necessary to use open ditches of sufficient size to carry the water coming to the drained land from adjacent territory. The size of the ditch necessary in such a case can be approximately estimated by observing the flow of water following a severe freshet. When the surface water from large areas is to be carried away it is best to secure the services of an engineer who, after making the necessary survey of the area to be drained, can compute the size of the ditch necessary.

In the case of comparatively level land, where it is impossible to establish an outlet for subsurface drainage, surface drainage should be made as effective as possible. This is especially necessary where the land is underlain by an impervious clay subsoil. It is often practical to use the common plow in ditching such level areas. The plowing should be done in long narrow lands, and the dead furrows should be carefully cleaned out to serve as drainage ditches. It is frequently necessary to cut ditches across from one dead furrow to another in order to drain a slight depression which would otherwise be filled with water. These narrow plow lands should usually be kept in the same position for two or three years in order to round up the back furrow somewhat and deepen the dead furrow, but they can not be kept longer than three years ordinarily without widening the dead furrow to an undesirable extent. After this the plowing must be reversed, and the first two furrows of the lands turned into the dead furrows. This method of surface drainage has its greatest objection, perhaps, in the difficulty which comes from working over the open-furrow ditches.

The timely use of a shovel or large hoe in the spring will greatly aid in removing the surface water coming from rain and melting snow.

Subsurface or underdrainage (Ref. No. 8, pp. 27–34).—Practically all underdrainage is now accomplished through the use of common porous clay tile or glazed tile, laid loose jointed so that the water may pass into the drains through the joints or where the tile meet. The glazed tile are usually more expensive than the porous, but they are also more durable. Factors of greatest importance to be determined in planning an underdrainage system are (1) depth at which the tile should be placed, (2) the available fall or grade of the tile, (3) the system to be used, (4) the distance apart of tile lines or laterals, and (5) the size of tile to be used.

Depth.—The depth for placing tile is dependent upon several things. First of all, tile must always be placed below the depth of tillage and also below the frost line. Freezing will crumble porous tile, and it causes heaving of the ground and displacement of the tile in any case. The depth to which tile should be placed varies also with the type of soil and the desired depth of water table. The

movement of water in silt loam, clay loam, and clay soils is essentially all through granulation spaces, as very little takes place between the finest soil grains. In such soils tile must not be placed much below the level to which granulation extends. This usually means about 3 to 3½ feet. Occasionally it is necessary for short distances to place tile much deeper in order to keep the necessary grade.

Grade.—The difference of levels between the outlet and the highest point of the drainage system divided by the distance between these positions naturally establishes the maximum grade possible. Where the fall is slight the minimum grade permissible for effective drainage depends largely upon the length of the drain and the size of the tile. Water will flow more rapidly in large tile having a given gradient than in small tile. Lateral or branch tile having a diameter of 3 or 4 inches may be laid with as little fall as 1 inch to 100 feet for several hundred feet in length, provided the soil is of a clayey nature. If laid in fine sandy soils, so that there is danger of the sand finding entrance to the tile through joints, the grade must be not less than 3 or 4 inches per 100 feet, in order that the current in the tile may be sufficient to keep it clean. Soil may often be kept from passing into the tile by placing straw or other similar material over the joints before covering the tile.

System (Ref. No. 8, pp. 38–43).—By "drainage system" is meant the arrangement of the lines of tile which are to collect the surplus waters from any piece of land. There are several of these systems. The one which should be used in any case will depend upon the shape, the size, and the surface topography of the area to be drained. In many instances two or more of these systems may be effectively combined.

Distance apart of laterals.—When wet lands are in the form of narrow runs or sloughs, tile ditches should be dug as nearly as practicable along the courses in which the water naturally runs, although it is frequently necessary to straighten these considerably. When broader areas are being drained, so that laterals or side branches of tile are necessary, the distance between these will be determined by the degree of drainage to be secured and by the character of the soil. In the case of fine-textured clay soils it is necessary to put tile drains as close as 2 rods apart in order to secure the thorough drainage necessary for garden or truck crops, though laterals placed 4 rods apart should give sufficient drainage for practically all staple crops. In wet sandy soils the laterals may be placed farther apart, though, as mentioned above, they must be of sufficient size to remove the water freely.

Size of tile (Ref. No. 8, p. 82).—In determining the sizes of lateral and of main tile to use under different conditions, certain principles

should be kept in mind. The quantity of water carried by any pipe or carrier of drainage is equal to the area of the cross section of the stream multiplied by its rate of flow. This rate of flow in a tile line will vary with the fall, the length of line, the size of tile, and the degree of smoothness of the inside of the tile. It is well to keep in mind that the cross sectional area of a tile varies directly as the square of its diameter. This means that, other things being equal, a 6-inch tile has about four times the water-carrying capacity of a 3-inch tile. It should also be kept in mind in this connection that the cost of tile does not increase in proportion to size. That is to say, 6-inch tile does not cost twice as much as 3-inch tile. Frequently 4-inch tile can be bought as cheap, or nearly so, as 3-inch, although their water-carrying capacity is nearly double that of the 3-inch. Again, the cost of digging the ditch and laying the tile, which is commonly of greatest consideration, is practically independent of the size of the tile to be laid. It is always best to be on the safe side with regard to the size of tile purchased for any drainage system. An estimate of the size of tile necessary for fields of different dimensions is given by Elliott (Ref. No. 8, p. 84).

Where the size of tile, or anything else in connection with drainage, is difficult to determine, it is advisable to consult the State agricultural college or a drainage engineer.

Laying out the drainage system.—After the lines along which tile are to be laid have been staked out by the use of laths or other stakes 2 to 3 feet in length, placed 50 feet apart, short stakes, called grade stakes, should be driven even with the surface of the ground near the lath. (Ref. No. 8, pp. 48, 63–65.) A line of levels should then be run along the grade stakes, beginning with the lower end at the level of the outlet. In recording the levels this first stake should be numbered zero (0). (Ref. No. 8, pp. 58–63.) By determining the difference in height between each succeeding pair of stakes the line of elevation of the surface of the ground is determined and may be platted on horizontally ruled paper. When this line of elevation has been drawn the fall available can be determined.

The next item to be found is the grade which can be used. (Ref. No. 8, pp. 68–74.) To do this, subtract the distance which the tile must be placed below the surface at the upper end, or at the point where the tile comes nearest to the surface, from the total height of the surface at that point above the outlet. This gives the fall which may be used by the tile through this distance. Ordinarily the gradient should be uniform, but where laterals join larger mains it is possible to use smaller gradients on the mains than are used on the laterals. Having determined the total fall in inches or hundredths of feet, divide this by the number of hundred feet in the length of tile to get the fall per hundred feet. Half of this will be the difference in

level of the bottom of the ditch between the stakes which are 50 feet apart.

The height of the bottom of the ditch or the grade line, above the outlet can now be determined for each grade stake. These heights should be written in a column opposite the elevations of the surface of the ground. By subtracting the elevation of the grade line from that of the surface of the ground, the depth of cut can be found at each stake. These depths can be written in proper order in a third column.

The construction of the ditch may now be undertaken. (Ref. No. 8, pp. 89–98.) This should be started at the lower end, or outlet. It is necessary now to have a method of determining exactly when the grade line or bottom of the ditch is reached. To do this, place strong stakes at each of the two lower stakes with a line between. This line is to be placed at a uniform height above the bottom of the finished ditch. A string may be adjusted at a convenient height of 5 or 6 feet above the bottom of the ditch by subtracting the depth of digging at each stake from the 5 or 6 feet decided on and measuring up from the surface of the ground this distance on the stake. Fastening the string at this point for each of the two stakes will bring the string exactly parallel with the bottom of the ditch and 5 or 6 feet above it.

Digging the ditch and completing the drain.—The tools necessary include a ditching spade with a blade about 8 inches wide, slightly curved, and square at the cutting edge; a long-handled pointed shovel; a tile scoop; and, if much tile is to be laid, a tile hook. A strong string is first stretched along the edge of the ditch to keep it straight. Digging begins at the lower end and proceeds upgrade in sections, removing the dirt to a spade depth at a time. The width of the ditch will depend on the depth but should be no greater than is absolutely necessary. Care must be taken not to remove dirt below the grade line. When the grade line is nearly reached over a distance of 6 or 8 feet the last thin layer of dirt is removed with the tile scoop, which produces a straight, smooth bottom on which the tile may be placed. Tile may be placed by hand, though if the ditch is deep and much is to be laid the tile hook will permit much more rapid and easy work. The tile should be placed so that they fit closely together end to end, and care must be taken whenever work is left for the night to have the upper end protected by a flat stone or otherwise so that much soil may not be washed in in case of rain. The tile should be covered immediately after laying to a depth of 2 or 3 inches after heavy soil or other material has been used over joints to prevent sand or other loose material from working into the tile. (Ref. No. 8, p. 99.) This is called blinding. The remainder

of the filling may sometimes be done quickly and efficiently with a team and scraper.

Cost and profits of drainage.—The final questions which are always considered in connection with any needed drainage are (1) the cost, and (2) whether the accruing profits from increased production will warrant the cost of putting in the drainage system. The conditions which determine these two factors are so varied that no discussion of the matter will be entered into in this lesson. The different items of cost and profit are separately considered by Elliott (Ref. No. 8, pp. 121–138) and should be carefully studied by those who contemplate carrying out a drainage project.

Drainage of irrigated and alkali lands.—It frequently happens in arid lands where irrigation is practiced that soil areas which are adjacent to or somewhat below the level of irrigation canals or irrigated fields, and which have been fertile and productive for years, finally become unproductive and practically useless for agricultural purposes. Investigation has shown that almost invariably the changed condition is due to the subsurface soil being water-soaked from seepage from irrigated areas or irrigation canals or from excessive use of irrigation water. These areas are often at considerable distances from the source of the trouble. Where such a condition exists the surface soil also frequently becomes laden with soluble salts which are harmful to the crops commonly grown upon the land. This is because the seepage and other waters have carried quantities of these salts in solution which later become deposited at the surface of the soil upon the evaporation of the salt solution. Such deposits of salts, including sulphate, chlorid, and carbonates of sodium, magnesium sulphate (epsom salts), calcium sulphate (gypsum), and calcium chlorid, are also commonly found in spots of the surface area of extremely arid lands not irrigated. This is because the rise of water from capillarity, leaving the salts deposited upon evaporation, exceeds the downward movements from the rainfall. Areas containing harmful quantities of soluble salts in the surface soil are called alkali lands. If sodium carbonate is present in considerable quantity the alkali is usually dark colored due to action of the alkali on organic matter and is known as black alkali. The sodium carbonate, besides being harmful to plant growth, often causes the soil particles to puddle and to form an impenetrable hardpan a few inches below the surface of the soil. White alkali is that in which sodium sulphate and similar neutral salts which do not blacken organic matter predominate. This is much less harmful than black alkali. Underdrainage is one of the best ways of preventing the accumulation of alkali in soils and of reclaiming watersoaked and seeped areas, it being frequently established as a

the excess of soluble salts to percolate through the soil and pass away in the drains. Where alkali spots occur in arid lands the most effective and certain relief is usually afforded by underdrainage combined with surface flooding. The few rains which occur in these places, or a flooding of the land where possible, will finally carry the excess of harmful soluble salts from the surface soils into the drains. Calcium sulphate (gypsum) is very advantageously applied to black alkali lands before flooding. This results in a chemical reaction yielding calcium carbonate and sodium sulphate, which is much less harmful than sodium carbonate and is readily removed by drainage.

The methods of underdrainage of irrigated and alkali lands differ from those used in humid sections.

EXERCISES, LESSON V.

Materials required.—Four boxes 1 foot square and 4 inches deep; a sufficient quantity of clay or silt loam to fill these boxes; a few small thermometers; three 3-inch unglazed tile; two tight wooden boxes 10 by 12 by 10 inches; a small quantity of paraffin or paint; paper, pencil, and ruler.

Influence of slope (Ref. Nos. 2, pp. 228, 229; 3, pp. 458, 459).—Fill two boxes, each 1 foot square and 4 inches deep, level full of the same kind of soil. Have the soil equally compact in both boxes. Place both boxes in the sunlight, so that the surface of the soil in one box will be at right angles to the rays, and in the other nearly parallel with the rays. After an hour or two compare the temperature of the two soils. Explain the differences. What are the advantages of a north slope as a site for an orchard?

Influence of water content.—Fill two boxes as in the preceding exercise with almost dry clay or silt loam. Compact soil equally in both boxes. Wet the soil in one box almost to saturation with water. The water used should be of the same temperature as the soil in the other box. Take the temperature of the soil in both boxes, then place them in the sun. After two or three hours compare the temperature of the soil in the two boxes. Which requires more heat to raise 100 pounds 1°, water or dry soil? Why should a low, wet soil be called a cold soil?

How tile works (Ref. No. 8, p. 28).—Secure three 3-inch unglazed tile and two tight wooden boxes about 10 by 12 by 10 inches. Cut two holes in opposite sides near the bottom of one and on opposite ends near the bottom of the other box large enough to allow the tile to enter. Place one tile in the first box so that the two ends will project from either side. Place the other two tile end to end with the joint in the middle of the box and the ends of the tile projecting from either end of the box. Make both boxes water-tight by means of paraffin or paint (do not seal the joint of the tile in the box containing the two tile), and fill each box with sandy soil. Saturate the soil with water and note results. Explain fully how tile works under field conditions. Are there any objections to glazed tile?

Two drainage systems.—A level field 80 rods long and 20 rods wide has a ditch 6 feet deep across one end. Draw out to scale of 5 rods to 1 inch two systems for laying out drains, namely, one with a long main and short laterals, and the other with a short main and long laterals Place the laterals in each case 4 rods apart.

Compare the number of rods of tile required for the two systems. Make computations from the drawings.

Principles of tile laying (Ref. No. 8, pp. 63–68).—An outlet ditch 6 feet wide at the bottom, 7 feet deep, and 20 feet wide at the top has a line of tile emptying into it 4 feet

below the grade stake No. 0 at the top of the ditch. The elevations above datum plane at the grade stakes are as follows: No. 0, 52 feet; No. 1, 52 feet; No. 2, 52.5 feet; No. 3, 52.75 feet; No. 4, 53.25 feet; No. 5, 54.25 feet; No. 6, 53.75 feet; No. 7, 54 feet; No. 8, 54 feet; No. 9, 54 feet; and No. 10, 53 feet.

(a) Draw a profile or cross section of the ditch and ground, showing the line of elevation of the surface of the ground. Use ruled paper having lines drawn $\frac{1}{4}$ inch apart each way. Let each $\frac{1}{4}$ inch on the horizontal lines represent 25 feet, and each $\frac{1}{4}$ inch on the vertical lines represent 2 feet.

(b) At grade stake No. 10 the tile was laid $3\frac{3}{4}$ feet deep. Determine the fall that was available. This line of tile was laid with a uniform gradient. Determine the fall in inches per hundred feet.

(c) Determine the grade line, or the height of the bottom of the ditch above the outlet at each grade stake. (Ref. No. 8, pp. 72–74.) Set these elevations down in a column opposite the elevations of the surface of the ground at each grade stake.

(d) Determine the depth of cut that was made at each grade stake. (Ref. No. 8, pp. 77–82.)

(e) On the profile map draw a line 5 feet above and parallel with the grade line from stations No. 0 to station No. 10. Let this line represent the line of sight formed by the string to aid in the construction of the ditch. (See p. 37.) Determine the height the string should be above each grade stake.

Field excursions.—(a) By the use of any convenient thermometer, the temperature of various soils may be compared; north slopes with south slopes, black and light colored soils, upland and lowland, drained and undrained lowland, sandy soil and clay or silt loam, loose and compact clay or silt loam. Explain all variations found.

(b) If convenient, make a trip to inspect some drainage systems. Make a sketch of the drained area and draw in the drainage system.

If convenient, in the spring compare the temperature of the soil above a line of tile with that midway between laterals.

Observe the natural drainage of any interesting area.

REVIEW QUESTIONS, LESSON V.

1. How is soil temperature related to fertility and the growth of crops?
2. Explain fully what becomes of the heat which is absorbed by the surface of the soil.
3. What factors influence the amount of heat which penetrates the subsoil?
4. Explain why frosts sometimes occur on poorly drained ground when they do not occur on well-drained ground?
5. Discuss the practical means of regulating soil temperature.
6. State several benefits which may be derived by good drainage of soils.
7. How can you tell whether the soil of a given field is well drained or not?
8. Describe a good method for the surface drainage of flat land which is nearly level.
9. Why is underdrainage by the use of tile more to be desired than surface drainage?
10. How does the water from the surface find its way into lines of tile?
11. What kind of soil is most difficult to drain by means of tile?
12. Estimate the slope in feet per mile necessary to permit good tile drainage on an 80-acre field?
13. What should the diameter of a main outlet of tile be on a field of 100 acres having a slope of 1 inch to 100 feet?
14. Define grade stakes, line of levels, grade line.
15. How should tile be laid? What is meant by blinding tile?

LESSON VI. THE NITROGEN SUPPLY OF THE SOIL.

(Ref. No. 2, pp. 110–119.)

As stated in Lesson II, nitrogen is one of the most important elements of plant growth. Nearly four-fifths of the atmosphere, or over 70,000,000 pounds over each acre of land, is nitrogen. While this is sufficient to support plant growth for thousands of years, yet atmospheric nitrogen can not be utilized directly in plant growth but must first be combined in the soil with other elements before plants can absorb it. It will be the purpose of this lesson to explain how the nitrogen of the air becomes transformed so as to be used by plants and to discuss briefly the practical means of maintaining the soil-nitrogen supply.

Combined nitrogen in the atmosphere (Ref. No. 1, p. 22).—From the decay of vegetable and animal materials, burning, electrical discharges, and other causes the atmosphere derives certain substances, among which are ammonia and nitric acid, both compounds of nitrogen. These gases are readily absorbed by the moisture of the atmosphere, and when this moisture condenses and falls as rain or snow it carries with it into the soil the nitrogen compounds which it contains. While the available nitrogen thus added to the soil is not large, yet it is an appreciable quantity and contributes in a small way to the soil's fertility.

The fixation of atmospheric nitrogen in the soil (Ref. No. 7, pp. 213–223).—The nitrogen of the soil which plants require comes ultimately from the atmosphere. A large supply of this nitrogen is collected from the atmosphere in the soil through the action of microorganisms called bacteria. The nitrogen-fixing bacteria of the soil may be divided into two classes. One class lives independently in the soil and secures nitrogen direct from the air for its growth. After these bacteria perform their life's work their bodies decompose and the combined nitrogen which they contain becomes available for the growth of plants. The amount of nitrogen fixed by this class of bacteria in ordinary cultivated soils has been estimated by different investigators at from 15 to 40 pounds per acre. Probably the latter figure is much above the general average, even under favorable conditions. The other class of nitrogen-fixing bacteria lives in connection with the roots of certain plants, viz, of the family of legumes, including clovers, alfalfa, beans, peas, and others. These bacteria form nodules or tubercles in which the chemical combination of nitrogen with other elements takes place and from which the host plant obtains much of its nitrogen for growth.

Inoculation (Ref. No. 7, pp. 223–228).—The bacteria which form tubercles on the roots of leguminous plants are generally different for different species of plants. Those which live on alfalfa, however, are

the same as those which live on sweet clover, and the nodule bacteria of the true clovers have also been found to be interchangeable for purposes of inoculation. The bacteria of cowpeas and soy beans are not interchangeable nor can they be used for inoculating any other of the leguminous plants. It often happens in a particular field that bacteria of the right kind are not present to form nodules on a species of legume which is being grown on the field for the first time. It is then necessary to supply these bacteria. This is done in two different ways:

(1) A culture of bacteria is used. This culture is made by transferring some bacteria from a plant nodule to a substance suitable for their growth. Under right conditions of temperature and air these bacteria multiply very rapidly, and in a comparatively short time the growing medium will contain millions of the microorganisms and is then called a culture. This culture growth of nodule bacteria needs to be handled by trained people in order that it may be kept pure. The United States Department of Agriculture, several of the State agricultural experiment stations, and many commercial firms have been growing cultures for agricultural use. These cultures, with directions for their use, are shipped direct to farmers by express or parcel post. The cultures are most commonly applied to seeds just before sowing. The methods are very simple and easy to carry out.

(2) Soil is used for inoculation. Soil to be used for this purpose should be taken from a field in which are growing, or have recently grown, healthy plants containing a good supply of the nodule bacteria desired. Nodules occur largely in the surface soil, ordinarily in the first 5 or 6 inches. In securing soil for inoculating, the first inch or so should be scraped away and the soil to the next few inches of depth should be taken. From 200 to 400 pounds per acre of inoculated soil can be scattered over a field before sowing and harrowed in, or the soil containing bacteria can be stirred up in water and after settling the liquid can be poured off and used to inoculate seeds much as the cultures are used. With either method of inoculation care must be taken not to permit too intense heat from the sun to kill the bacteria. This can be avoided by harrowing under the seeds or soil-carrying inoculation soon after sowing them, or by doing the work early in the morning or late in the afternoon.

Amount of nitrogen fixed in the soil by legumes.—The fixation of nitrogen through the action of tubercle-forming organisms growing on the roots of legumes is the only practical method available to the farmer for storing this essential element in the soil. It must not be supposed, however, that all the nitrogen used by leguminous plants in their growth is secured in this way from the nitrogen of the soil air. Soluble nitrates of the soil are absorbed by growing clover and alfalfa, for example, just as they are by corn and cotton. But while

corn, cotton, and other nonlegumes secure all of the nitrogen from the soil for their growth, clovers, alfalfa, and other legumes secure a substantial part of their nitrogen by fixation from the air. Since there is always under field conditions a larger or smaller amount of nitrogen compounds made available to legumes, it is extremely difficult to determine just how much is fixed from the air. Under conditions of average fertility it is probable that about one-third of the nitrogen used by clover or alfalfa is taken direct from the soil, while about two-thirds is secured from the nitrogen of the air in the soil. When these crops are cut for hay, about one-third of the total amount of the nitrogen contained in the entire plant is left in the roots and stubble and about two-thirds is removed in the hay. Figuring from the above estimates, when a crop of clover or alfalfa is removed from the land the soil is left with practically the same amount of nitrogen that it had before the crop was grown. This, however, does not take into account what is lost by leaching. Cowpeas, soy beans, and other legumes restore to the soil from roots and stems a somewhat smaller percentage of nitrogen than do the clovers and alfalfa. When leguminous crops, therefore, are sold from the farm there results at least no gain of nitrogen to the soil. On the other hand, if these crops are fed to stock and the manure produced returned to the land, much of the nitrogen contained in the crops will go back to the soil and an actual increase of the nitrogen content of the farm will result. But when only corn and other grains or hay from timothy and other nonlegumes are grown, there results a positive gradual loss in the nitrogen content of the soil, no matter what may be the disposition of the crops.

Nitrification (Ref. No. 4, pp. 135–140).—Nitrogen is used for growth by plants in the form of chemical compounds called ammonia and nitrates. It is now known that rice takes up ammonia directly, while, as far as is known, all other farm crops absorb nitrogen chiefly in the form of nitrates. Organic matter can not, therefore, be utilized for plant growth until it has first undergone a process of decomposition. This decomposition is caused by microorganisms, or bacteria, living in the soil, which use the organic matter, mostly vegetable, for their nourishment and produce as by-products ammonia and nitrates, which can then be absorbed by plants. The normal process of decomposition of organic matter and the formation of nitrates through bacterial action is called *nitrification*. These organisms perform their work only under favorable conditions of moisture, aeration, and temperature. Nitrification is twice as rapid at 70° as it is at 50° and twice as rapid at 90° as it is at 70°, but the maximum temperature is probably between 95° and 100°, and if a much higher temperature is reached the bacteria do not grow well. If the soil is poorly aerated and water-soaked from a lack of proper drainage, an

abnormal decomposition takes place, through bacterial action, resulting in a loss of free nitrogen from the soil. Such an abnormal decomposition is called *denitrification*. An acid condition of the soil is unfavorable, also, to nitrification. The farmer should recognize that suitable conditions must be provided for normal bacterial growth in the soil if good crops are to be expected.

Commercial materials containing nitrogen (Ref. No. 1, pp. 190–196; or No. 7, pp. 244–260).—Besides the natural methods discussed above of keeping up the nitrogen supply of the soil, there are many commercial products on the market which are used to a considerable extent for certain soils and crops. These include mineral salts, together with waste products of both animal and vegetable origin. The principal mineral salts of nitrogen used on soils are sodium nitrate and ammonium sulphate, together with calcium cyanamid and calcium nitrate, which have recently been manufactured from atmospheric nitrogen.

Cottonseed meal is the principal organic source of nitrogen used as a fertilizer in the United States. In fact, it is used to a larger extent in this country than any other kind of nitrogenous fertilizer, notwithstanding the fact that it is also a valuable stock food for which the demand is steadily increasing.

The commercial animal products used as fertilizer include slaughterhouse refuse, especially dried blood and tankage; fish not valuable for human food, which has been prepared for use as fertilizer by cooking and extraction of oil; bird guanos; and stockyard manure. Peruvian guano formed from the excrement of birds deposited in large quantities on islands off the coast of Peru is rich in nitrogen and was once extensively used in this country, but the original deposits are now so nearly exhausted that there is little or none of the material available for export.

Of the mineral nitrogen salts, ammonium sulphate is used to a considerable extent in this country. Its long-continued use has been found to produce unfavorable soil conditions, which, however, are easily corrected by applications of lime. A mineral material largely used to supply nitrogen to soils is sodium nitrate or Chile saltpeter, so-called because it is obtained mainly from the nitrate deposits of Chile. The great advantage of sodium nitrate as a plant food is that it is readily soluble in water and quickly becomes available to growing crops. When applied to a poor soil its effect can usually be quickly seen in the rapid growth and the rich green color which the plants take on. A disadvantage in the use of this material is its tendency to leach from the soil, as noted in a previous lesson. Sodium nitrate, and other products rich in nitrogen as well, must be applied to the soil with much knowledge and skill if they are to prove profitable. Usually from 100 to 200 pounds per acre of the nitrate is used, and

it is often well to make an application at a time when the crop is in especial need of help or stimulation in its growth.

Need of decaying vegetable matter in the soil.—Doubtless one of the greatest needs of the soils of the United States is more nitrogen through the growth of leguminous crops. This is especially true in the South, where long summers and much sandy soil cause the vegetable matter quickly to become depleted. Growing legumes for green manure, or, preferably, feeding the legumes and returning the manure to the soil, are the cheapest and most effective ways of supplying nitrogen for staple crops. Other advantages which green manure or barnyard manure have over commercial nitrogenous substances in the soil are: (1) They do much to maintain the moisture content; (2) they improve the texture; (3) they increase the temperature; and (4) they promote bacterial action. These advantages should never be overlooked in farm practice. Some of these benefits to the soil from decaying vegetable matter have been mentioned in previous lessons, but they will bear repetition.

EXERCISES, LESSON VI.

Materials required.—Four boxes; some poor, sandy soil; a few peas, oats, or grains of corn; sodium nitrate, ammonium sulphate, and pulverized limestone.

Leguminous plants.—If conditions permit, carefully dig up different species of leguminous plants and examine the roots for nodules. If plants are carelessly removed from the ground the nodules will be pulled off and remain in the soil. If plants are taken up with a spade or shovel so that considerable earth remains on the roots, and then if the soil be very carefully washed away, an examination of the fine roots will show the nodules. These will vary on different legumes from the size of a pinhead to that of a small pea, or even larger. If plants can not be dug out of doors, peas or beans planted in a box and kept growing well will show the nodules after a few weeks.

Inoculation.—It will be found interesting as a field test to sow two strips side by side of some leguminous plant not commonly grown in the community, inoculating the seed used for sowing one strip and sowing the other strip from uninoculated seed. Cultures for inoculation may be secured by applying to your State experiment station or to the United States Department of Agriculture, Washington, D. C. After growing some six weeks the roots of plants from the two plats should be carefully examined for nodules. After two or three months of growth note whether there is a difference in the growth of plants on the two plats.

Salts containing nitrogen.—Fill four boxes with poor sand. Plant either peas, oats, or corn in all four boxes. Keep warm and moist until the seeds are up. Mix into the soil of one box a good sprinkling of sodium nitrate; mix a like quantity of ammonium sulphate into the soil of the second box, and ammonium sulphate and powdered limestone into the soil of the third; leave the fourth box undisturbed. Keep all the plants in good condition for growth and watch for a few weeks. Note results.

PROBLEMS.

1. A 30-bushel wheat crop removes from 1 acre about 48 pounds of nitrogen; a 50-bushel oat crop removes about 50 pounds; and a 65-bushel corn crop removes about 85 pounds of nitrogen per acre. How many pounds of nitrogen are removed from the soil on a grain farm where 30 acres of wheat are raised averaging 20 bushels per

acre, 25 acres of oats averaging 40 bushels per acre, and 50 acres of corn yielding 52 bushels of shelled corn per acre?

2. A clay or silt loam soil weighs in round numbers 2,000,000 pounds per acre, 8 inches deep. How many pounds of nitrogen are contained in an acre 8 inches deep of a fertile clay loam that analyzes 0.25 per cent of nitrogen? (a) How many 65-bushel corn crops will the nitrogen contained in an acre of this soil supply?

3. An acre of sand 8 inches deep weighs, in round numbers, 2,500,000 pounds. What is the nitrogen content of an acre of poor sand that analyzes 0.04 per cent nitrogen?

4. An acre of peat soil 8 inches deep weighs, in round numbers, 350,000 pounds. How many pounds of nitrogen are contained in an acre 8 inches deep of a soil of this kind that analyzes 2½ per cent nitrogen?

5. A certain silt loam contains 0.2 per cent nitrogen and a peat 3 per cent. In comparing these percentages, how may times more nitrogen are contained in the peat than in the silt loam?

(a) In comparing the actual number of pounds per acre 8 inches, how many times more nitrogen does the peat contain than the silt loam? Why this difference?

6. One ton of red-clover hay contains about 40 pounds of nitrogen, and 1 ton of alfalfa hay contains about 50 pounds. How many pounds of nitrogen are contained in 30 acres of clover yielding 2 tons per acre and 20 acres of alfalfa averaging 5½ tons per acre from three cuttings?

(a) How many pounds of nitrogen can reasonably be assumed to have been fixed from the air by these two crops?

(b) At 15 cents per pound what is the value of the nitrogen contained in 5 tons of alfalfa hay?

(c) Wheat bran contains 2.5 per cent nitrogen. How much bran is equivalent to 1 ton of alfalfa in nitrogen content?

7. How many square inches of air over 1 acre?

8. Atmospheric pressure averages about 15 pounds per square inch. How many tons of air over 1 acre?

9. About four-fifths of the atmosphere consists of nitrogen. How many tons of nitrogen over 1 acre? Do you think legumes will ever run short of this element in their work of nitrogen fixation?

REVIEW QUESTIONS, LESSON VI.

1. Discuss fully the fixation of nitrogen in the soil by nodule bacteria.

2. Name some leguminous plants. In what particulars, from the standpoint of soil fertility, do they differ from nonleguminous plants?

3. Explain what is meant by inoculation of soils.

4. What conditions affect the amount of nitrogen fixed by legumes?

5. About how much nitrogen is fixed by a 2-ton clover crop?

6. Explain fully how legumes may be made of most use in increasing the amount of nitrogen in the soil of a farm.

7. What is meant by nitrification, and how does it differ from nitrogen fixation?

8. Name some of the commercial materials used to increase the nitrogen content of the soil.

9. Compare the value of these commercial materials with the products of vegetable decay in general farm practice.

10. Is all vegetable matter in soils helpful in supplying fertility? Explain.

11. May soils be considerd inexhaustible in fertility?

12. Explain fully why a given soil may produce a large growth of native vegetation while the same soil after being brought under cultivation may fail to produce a large yield if the crops are removed from the land each year.

LESSON VII. THE PHOSPHORUS AND POTASSIUM OF SOILS.

The mineral elements of plant food in the soil which are most apt to be so low as to limit crop production are phosphorus and potassium (see p. 11). These elements, it will be remembered, come from the disintegration of rock materials. The total phosphorus and potassium content of a soil, therefore, depends primarily upon the kind of rocks from which the soil was formed. On the other hand, the quantity of phosphorus or potassium available to plants is not accurately measured by the total quantity of these elements in the soil, but depends much upon soil management. A soil may be rich in total phosphorus and potassium and yet crops may not be able to secure sufficient of these elements for large yields. The quantity of decaying vegetable matter in the soil has much to do with the quantity of mineral elements available to plants, but if a soil is low in phosphorus or potassium, or if the system of farming is such as to draw heavily upon these elements, materials rich in available phosphorus and potassium compounds may be added.

Any material which adds to the fertility of the soil is a fertilizer. This term, however, is more commonly applied to commercial materials used for this purpose, especially when the product contains two or more of the essential elements of plant growth. The phosphorus content of fertilizers is commonly expressed in textbooks and fertilizer analyses as phosphoric acid and the potassium content as potash. To think in terms of phosphorus, the compound phosphoric acid may be reduced to phosphorus by multiplying by 0.4366; potash may be reduced to the element potassium by multiplying by 0.83.

Phosphorus in the soil (Ref. No. 5, pp. 183, 184).—The proportion of this element in the most common soils of the United States is very small. The total amount on the average is from 0.05 per cent to 0.1 per cent. In many cases it is as low as 0.02 or 0.03 per cent. Since the soil of the surface, 8 inches, in which most of the organic matter occurs, weighs about 2,000,000 pounds on an acre, this means that there are normally between 400 to 2,000 pounds of phosphorus per acre, which constitutes most of the supply which can be made available to crops. Agricultural crops on the average take from 8 to 10 pounds of phosphorus per acre annually. The total supply of phosphorus in the soil to the depth of 8 inches would be, on this basis, sufficient to meet the needs of crops for from 50 to 250 years. This period would be much shorter in case of low phosphorus content or larger yields. Of course, it is probable that some of the phosphorus in the soil below a depth of 8 inches can be drawn on, but even if we assume that a considerable amount comes from below 8 inches, it is still evident that if the phosphorus absorbed from the

soil by crops grown on it is continually removed from the farm by the sale of crops, the supply will become depleted and phosphorus will become the limiting factor in crop production. In many instances this is now the case.

Phosphorus taken from the soil.—Most of the phosphorus absorbed by plants in their growth goes to the seed, so that when grain or seed is sold much of this element is removed from the soil. Likewise, when crops are fed to animals much of the phosphorus goes into the bones and milk, and if the animals or milk are sold from the farm considerable phosphorus is lost. It is evident also that the amount of phosphorus sold from the farm will vary greatly with the type of farming practiced. Grain raising is most apt to deplete the supply of phosphorus, since large quantities of this element are removed in the seed. The handling of live stock, especially if young animals born on the farm are raised and sold when they reach maturity, also removes considerable phosphorus. Dairy farming, in which it is customary to use a good deal of feed brought from outside of the farm and to sell butter fat which contains only a small amount of this element, removes much less; but even in dairy farming it must be recognized that there is some loss in the bones of old cows and in the milk, as well as by unavoidable leaching in the manure. In practice, these losses can be made good only by the purchase of phosphorus-bearing materials or of feeding stuffs which contain this element.

PHOSPHORUS-BEARING MATERIALS.

(Ref. No. 1, pp. 201–208; or No. 3, pp. 511–518; or No. 5, pp. 183–193; or No. 7, pp. 261–277.)

Besides what is naturally in the soil, the principal phosphorus-bearing materials are, (1) the bones of animals, (2) natural beds of calcium phosphate, and (3) phosphatic iron ores.

Bone phosphates.—A very limited supply of phosphorus for soil improvement comes from the bone meal prepared by packing houses. This, of course, comes originally from the soil. Raw bone contains from 9 to 11 per cent of phosphorus, but in preparing it for use on soils it is now usually steamed or otherwise treated to remove the bulk of the organic matter, and then ground. Steamed bone meal contains from 12 to 14 per cent of the element phosphorus. Sulphuric acid is sometimes added to bone meal. The resulting acidulated bone phosphate or so-called dissolved bone is more readily available than the raw bone. This product contains about 7 per cent of phosphorus and 2 per cent of nitrogen. Bone tankage, a by-product of the packing houses, contains $2\frac{1}{2}$ to 9 per cent of phosphorus. Unacidulated bone phosphate is not readily soluble in water and becomes available to crops slowly, so that rather larger

quantities of the element must be applied in this form than it is expected a single crop will remove. When 300 to 400 pounds of ground steamed bone meal are used per acre, it will supply sufficient phosphorus for from three to five crops, depending largely on kind and yield.

Natural phosphates.—The chief supply of phosphorus for soil improvement is from natural phosphate beds. These are widely distributed over the earth, the most important deposits being in the United States, Canada, France, Spain, Norway, and north Africa. More than half of the world's output of these phosphates is produced in the United States. The principal phosphate beds in this country which have been worked are in Florida, Tennessee, and South Carolina. Enormous deposits, however, have recently been discovered in adjacent parts of Utah, Idaho, and Montana. Natural phosphate deposits are prepared in two ways for application to the soil, (1) by grinding the material to an extremely fine condition which is known and sold as raw phosphates or floats; and (2) by treating the ground material with sulphuric acid so as to form acid phosphate or superphosphate.

Raw phosphate or floats.—Rock phosphate varies greatly in content of phosphorus, ranging from 9 to 18 per cent, though the usual limits are 11 to 15 per cent. Even when ground to extreme fineness this material is dissolved in the soil with very great difficulty and becomes available to crops slowly. Certain crops, however, have greater power to secure their phosphorus from this source than others. The chief process by which this material is made available is through the action of carbon dioxid set free by the decomposition of organic matter in the soil. It is very necessary, therefore, that this material be used only when it is intimately mixed with some form of actively decomposing vegetable matter. This occurs when it is thoroughly incorporated with barnyard manure or applied as a top-dressing on some green-manuring crop which is being plowed under, or is applied to a soil naturally containing large quantities of vegetable matter, such as peat or muck soils. When used under these conditions rock phosphate is often as profitable to crops having a long period of growth as either of the other forms mentioned. From 500 to 1,000 pounds per acre of finely ground phosphate is commonly applied once in three or four years.

Acid phosphate.—In order to make the phosphorus or rock phosphate more readily available than in its natural condition it is very generally treated with sulphuric acid. Crude sulphuric acid and raw rock phosphate are mixed in about equal proportions, so that the percentage of phosphorus in the mixture is about one-half that in the raw rock phosphate, though essentially all of it is made available to

crops. The reaction of the sulphuric acid with the calcium phosphate produces in addition to acid phosphate, calcium sulphate (gypsum), to which may be attributed some of the benefit secured by the use of the acid phosphate.

On account of its ready availability, acid phosphate may be used in moderate amounts so as to supply only the phosphorus needed by the crops of one or two years. Since it usually has 6 or 7 per cent of phosphorus, crops requiring from 12 to 14 pounds of that element would need 200 to 300 pounds of the acid phosphate to furnish sufficient phosphorus for a single year. Where the crops grown are such as require large supplies of this element, as in the case of clover, alfalfa, cabbage, turnips, and certain other crops, a larger application would be better.

Slag phosphate.—When pig iron from ores rich in phosphorus is converted into steel by the basic process in which an excess of lime is used, a by-product, or basic slag, results. When produced by proper methods, the basic slag contains about 8 per cent of phosphorus, together with a considerable quantity of lime, from which the slag may derive a part of its benefit to the soil. Slag phosphate is produced in large quantities in Europe, and to some extent in the United States.

Potassium in the soil (Ref. No. 4, pp. 214, 215).—Potassium exists in large quantities in most soils, having been left as a residue from the incomplete decomposition of minerals rich in that element such as feldspar and mica. The total amount in sand, silt, and clay soils varies from 0. 5 to 2.5 per cent. A large part of this is still combined with silica in an extremely insoluble form, and it becomes available only through the further decomposition of these silicates. The availability of these great natural stores of this element depends largely upon the presence of an abundant supply of organic matter in the soil. Peat and muck soils, which have been chiefly formed from vegetation which has grown in water or in very wet marshes, have usually had a considerable portion of the potassium leached out after the death of the plants, so that the resulting peat or muck contains relatively small quantities of this element. The average content of potassium in muck and peat soils is only from one-twentieth to one-fiftieth of that contained in upland earthy soils. It is true that the rapid decomposition of the organic matter of such soils which takes place when they are drained and broken generally leads to a fair supply of this element for a few years, but in practically all cases heavy applications of potassium are required sooner or later, and of phosphorus also in most cases.

Potassium taken by crops (Ref. No. 4, p. 213).—Cereal crops require relatively small amounts of this element, ranging from 20 to 40 pounds per acre annually, of which from one-third to one-fifth only is con-

tained in the seed, the greater portion being left in the stalk or straw. Corn, potatoes, cabbage, and most truck crops require relatively large supplies, varying from 60 to 100 pounds per acre, depending on yield and somewhat on kind of plant. Tobacco, for instance, requires unusually large quantities of this element. The legumes, especially clover and alfalfa, which are used as hay, also contain large quantities, alfalfa frequently removing as high as 150 pounds of this element per acre in the 5 or 6 tons grown annually. Essentially all the potassium which truck crops and hay contain is removed from the farm when they are sold, while in the growing of cereals of which only the seed is usually sold, relatively small amounts of this element are lost from the farm.

Soils needing potassium (Ref. No. 1, p. 197).—From the foregoing it is evident that potassium-bearing materials are especially needed under the following conditions: (1) On muck and peat soils; (2) on upland soils low in potash and of coarse texture, such as sandy soils; and (3) in the growth of certain truck crops and of hay, which require unusually large quantities of this element.

Potassium-bearing materials (Ref. No. 7, pp. 278–287).—The most important sources of commercial potassium are the deposits of the Stassfurt region, in Germany. (Ref. Nos. 4, pp. 216–218; 5, pp. 529–531.) The potassium exists in various salts, so that the raw product as mined varies greatly in the amount of potassium contained. Some of these salts are used directly upon the soil where the distance of haul is not too great. Kainit, one of these salts containing from 9 to 10 per cent of potassium, is very largely used in Germany and is imported to some extent into this country. The salts of potassium used most as fertilizers in this country, both alone and in the manufacture of complete fertilizers, are potassium sulphate and potassium chlorid (muriate of potash). It has been generally held that the chlorin in the latter material is injurious to certain crops, especially to potatoes and tobacco, and for these crops the use of the sulphate is usually advised.

The use of potassium salts.—When potassium salts must be depended upon to supply all or essentially all the potassium, from 100 to 300 pounds of muriate of potash must be used annually. Such crops as potatoes, sugar beets, and cabbage require relatively larger supplies than grain. Larger quantities should be used on sandy, muck, or peat soils than on loam or clay-loam soils. The salts should be spread evenly and should be well worked into the soil. Where potatoes are to be grown the muriate should be applied the fall before or the sulphate of potash used in the spring. Heavy applications of muriate in the spring tend to roughen the skin of the potato. When a large part of the crops grown on the farm are fed

to stock and the manure returned to the soil, very little potassium need be purchased except on farms located on marsh soils.

EXERCISES, LESSON VII.

Materials required.—Sodium nitrate, muriate of potash, sulphate of potash, kainit, acid phosphate, rock phosphate, bone meal, and of as many other fertilizer salts as possible; four 3-gallon crocks; ½ bushel of moist sand or loam; a handful of corn; a small teaspoon, a tablespoon; two or three cups.

Solubility of fertilizer materials (Ref. No. 4, p. 240).—Place a teaspoonful of sodium nitrate in a cup and fill the cup two-thirds full of water. Stir for a few minutes. What happens to the fertilizer? When is a fertilizer considered soluble? Try the same test on muriate of potash, sulphate of potash, kainit, acid phosphate, rock phosphate, and bone meal.

Fertilizer material in hill versus broadcast application.—Fill four 3-gallon crocks with moist clay or silt loam soil and treat as follows:

(a) In the center make a hole about 2 inches deep and place in it three kernels of corn. On top of the corn place a tablespoonful of muriate of potash or any one of the other potash fertilizers; cover and water when necessary.

(b) Repeat as in (a), but place the tablespoonful of the same kind of fertilizer 2 inches deep and 3 inches away from the corn kernels. Cover and water when necessary.

(c) Repeat as in (a), but use only a small teaspoonful of the same kind of fertilizer.

(d) Determine the area of soil surface in this crock and apply as much muriate of potash as is equivalent to a 400-pound application per acre. Mix the fertilizer thoroughly with the top 4 inches of soil and plant three kernels of corn 2 inches deep.

Give all the crocks the same care and note carefully the effect of the different treatments upon the growth of the corn.

(e) A small teaspoonful of potash fertilizer weighs one-fourth of an ounce. Calculate the amount of fertilizer required per acre if each hill were treated as in crocks (a) and (c), the corn being planted in hills 3½ feet each way.

(f) Similar tests may be made, using phosphate materials or mixed materials. What conclusions may be drawn from the results of these tests?

PROBLEMS.

1. An acre of dry sand or sandy soil 8 inches deep weighs in round numbers 2,500,000 pounds; a clay or silt loam, 2,000,000 pounds; and a peat, 350,000 pounds. How many times heavier is sand than peat?

2. A productive silt loam analyzed 0.11 per cent phosphorus. How many pounds of this element are contained in an acre 8 inches deep?

3. A 75-bushel corn crop removes from an acre approximately 16 pounds of phosphorus. How many such crops of corn can be supplied by the total amount of phosphorus in an acre 8 inches of that fertile silt loam?

4. A certain clay loam contains 0.049 per cent phosphorus. How many more pounds of this element are contained in an acre 8 inches of the fertile silt loam than in this clay loam?

5. How many 75-bushel corn crops will the phosphorus in an acre 8 inches of the clay loam supply? Is any soil able to produce a 75-bushel corn crop every year until the soil supply of phosphorus is entirely exhausted? Explain. (Ref. No. 5, pp. 107, 108.)

6. A silt loam soil was cropped almost continuously for 63 years. It is now in a badly exhausted condition and analyzes only 0.04 per cent phosphorus. A sample of this same soil which was never cropped contained 0.074 per cent phosphorus.

Determine the apparent average annual loss of this element from the soil during those years.

7. One ton of clover hay contains approximately 5 pounds of phosphorus and timothy hay about $2\frac{1}{3}$ pounds per ton. How many pounds of phosphorus are sold from the farm when a farmer sells 30 acres of clover averaging $1\frac{1}{4}$ tons per acre and 25 acres of timothy averaging $1\frac{1}{2}$ tons of hay per acre? What is the value of this phosphorus at 10 cents per pound?

8. One ton of wheat bran contains about 25 pounds of phosphorus and cottonseed meal the same amount. How many pounds of phosphorus does a farmer bring to his farm when he buys 20 tons of bran, 8 tons of cottonseed meal, and 15 tons of clover hay? Is all of this phosphorus added to the soil?

(*a*) The loss of phosphorus in the feeding transaction may be considered 20 per cent, the manure being hauled directly to the field. How many pounds of phosphorus will this farmer add to his soil through the purchase of these feeds?

9. Twenty-five per cent phosphoric acid is equivalent to what per cent phosphorus (P)? Fifty pounds of the compound phosphoric acid (P_2O_5) is equivalent to how many pounds of the element phosphorus (P)?

10. One phosphorus fertilizer contains 14 per cent phosphorus, while another is marked to contain 30 per cent phosphoric acid. Which contains the more phosphorus, and how much more?

11. When rock phosphate containing 30 per cent phosphoric acid can be delivered for $8 a ton, what is the cost of 1 pound of phosphorus?

12. When acid phosphate analyzing 16 per cent phosphoric acid can be had for $16 a ton, how many pounds of phosphorus can be purchased for a dollar? Compare this with rock phosphate. Which of these two fertilizers is soluble?

13. The phosphorus contained in rock phosphate analyzing 13 per cent phosphorus and applied at the rate of 1,000 pounds per acre is sufficient to supply about how many 75-bushel corn crops?

14. How much basic slag analyzing 8 per cent phosphorus must be added per acre to return to the soil approximately the amount of phosphorus removed by three clover crops averaging 2 tons of hay per acre, two 75-bushel corn crops, and one crop of timothy hay averaging $1\frac{1}{2}$ tons per acre?

15. One thousand pounds of milk contains 0.8 of a pound of phosphorus. How much phosphorus is contained in the milk produced by one cow in a year if she averages 30 pounds of milk per day?

16. How many pounds of potassium are contained in a heavy clay loam analyzing 2.5 per cent potassium? In a peat containing 0.5 per cent potassium?

17. A poor, sandy soil analyzed 0.68 per cent potassium, while a peat analyzed 0.3 per cent of this element. In comparing the percentages, what per cent more of potassium does the sand contain than the peat?

18. In comparing the actual number of pounds in an acre 8 inches deep, what per cent more of potassium does the poor sand in problem 20 contain than the peat? Explain the different results obtained in these two problems.

19. A 1,600-pound tobacco crop removes from 1 acre about 75.5 pounds of potassium. How many such crops will the potassium supply that is contained in an acre 8 inches deep of a silt loam analyzing 2 per cent potassium?

20. A 4-ton alfalfa crop removes from 1 acre about 95.5 pounds of potassium. What is the value of the potassium contained in 40 tons of alfalfa hay when 1 pound of this element is worth 6 cents per pound?

21. Sixty-five pounds of potash (K_2O) is equivalent to how many pounds of potassium? Fifty per cent potash is equivalent to how many per cent potassium?

22. A man can buy muriate of potash analyzing 43 per cent potassium for $45 per ton and kainit containing 12 per cent potassium for $15 a ton. Both are soluble fertilizers. Which will give him the more potassium for his money?

REVIEW QUESTIONS, LESSON VII.

1. How many pounds of phosphorus are there in the surface 8 inches of a silt loam soil if the chemical analysis shows that it contains 0.07 per cent of this element?
2. State ways in which phosphorus may be lost from the soil.
3. How may these losses be replaced?
4. Why is dairy farming less liable to exhaust the phosphorus of the farm than grain raising?
5. Name the chief sources of phosphorus used for fertilizers.
6. Mention the principal kinds of phosphate fertilizers available for use in this country.
7. Which contains more phosphorus, rock phosphate or acid phosphate?
8. How should rock phosphate be used? How may acid phosphate be applied?
9. Do legumes such as alfalfa and clover remove phosphorus from the soil?
10. How is the phosphorus content of phosphate fertilizers commonly expressed?
11. In what part of the plant is most of the potassium left when the crop matures?
12. How does potassium differ in this respect from phosphorus?
13. How much potassium is usually removed from an acre by a crop of corn?
14. What plants draw most heavily on this element?
15. How does the amount of potassium compare with that of phosphorus in ordinary clay loam soil?
16. What kinds of soil are most lacking in potassium?
17. What is the chief source of potassium fertilizers, and what are the most important kinds?
18. About how much muriate of potash would you apply to muck soils on which you expected to grow a heavy crop of cabbage?
19. When should muriate of potash be applied to ground on which potatoes are to be planted?
20. Under what conditions is it unnecessary to use potassium fertilizers on heavy soils?

LESSON VIII. MANURES AND FERTILIZERS.

In the general use of the terms, manures are thought of as the waste materials from the care of live stock, while fertilizers include commercial materials of value to the soil because of their nitrogen, phosphorus, and potassium content. In this lesson we shall include as manures crops which are grown and returned to the soil, either indirectly through animal excrement and straw or other material used as bedding, or directly by returning the crop without harvesting solely for purposes of soil improvement. These subjects will be treated, respectively, under the headings of barnyard manure and green manures. The use of manures as soil builders has a distinctive advantage over commercial fertilizers because of the value which results from the decaying vegetable matter in addition to the nitrogen, phosphorus, and potassium which they furnish to the soil. Commercial fertilizers stimulate the growth of plants by supplying the three essential elements noted above in a concentrated and usually available form. The intelligent combined use of the two is best for both soil and crops.

BARNYARD MANURES.

(Ref. No. 1, pp. 113–121; or No. 7, pp. 316–347; or No. 9, pp. 229–236; or No. 6, pp. 131–148; No. 5, pp. 541–543; No. 4, pp. 158–160.)

Materials retained and voided by animals.—Much of the plant food removed from the soil by crops may be returned in the manure from animals to which the crops are fed. The actual amount of plant food so returned depends on the quantity absorbed by animals in their bones and flesh or converted into milk, and on the loss from the manure before it is returned to the soil. The more digestible the food and the younger the animal the larger is the portion retained in the form of bone and flesh. Hall, in England, found that when linseed cake was fed to fattening steers and milch cows, the distribution of the nitrogen, phosphorus, and potassium were as shown in Table III.

TABLE III.—*Distribution of nitrogen, phosphorus, and potassium contained in linseed cake when fed to fattening oxen and milch cows.*

	Nitrogen.	Phosphorus.	Potassium.
	Pounds.	*Pounds.*	*Pounds.*
Content of 100 pounds of linseed cake	4.75	0.872	1.162
When fed to fattening oxen:			
Retained in meat	.21	.061	.017
Voided in urine	3.88	.039	.913
Voided in dung	.66	.772	.232
When fed to milch cows:			
Retained in milk	1.33	.218	.116
Voided in urine	2.75	.031	.872
Voided in dung	.67	.623	.174

This table is of special value in showing the comparative quantities of nitrogen, phosphorus, and potassium retained in meat and milk; also in the comparative quantities of these essential elements shown to be voided in liquid and solid excrement. It emphasizes the cost of producing milk from the fertility standpoint, and it clearly shows the importance of saving the liquid manure and returning it to the soil. Hopkins shows that as a general average for dairy farming, cattle feeding, and sheep feeding, practically one-third of the organic matter, three-fourths of the nitrogen, and three-fourths of the phosphorus contained in the feed and bedding are recovered in the total manures. Nearly all of the potassium may be recovered except that sold in milk.

Value of barnyard manure.—From a large number of chemical analyses it has been determined that the average sample of fresh manure, including bedding used in absorbing the urine, contains about 10 pounds of nitrogen, 2 pounds of phosphorus, and 8 pounds of potassium per ton of material, varying with the age of the animal and the feed. Estimated upon the fertility value of the three essential elements nitrogen, phosphorus, and potassium, fresh barnyard

manure is worth from $2.50 to $2.75 per ton. After being exposed in the open yard for a few months, 2 tons of fresh manure decomposes to about 1 ton, with an analysis showing 10 pounds of nitrogen, 3 pounds of phosphorus, and 8 pounds of potassium, having a fertilizer value of from $2.60 to $2.85 per ton. These estimates do not include the value to the soil of the organic matter furnished by manure. The comparative value of manures voided by different animals will be found in the references. It is highly important in farm practice to understand that the kind of feed given to farm animals has a very close relation to the value of the manure voided. The richer the feed in nitrogen content, the more valuable will be the excrement produced. Therefore, one who winters live stock largely on corn fodder and straw will have much less valuable manure to return to the soil than one who adds clover hay, alfalfa, or grain to the feeding ration.

Losses from barnyard manure.—The losses from manures on farms of the United States is hundreds of millions of dollars annually. This is poor economy, considering the needs of the farms from which this immense loss occurs and the fact that much of it could be avoided by good management. The losses occur largely in two ways: (1) From liquid manures not being saved, and (2) from storing and exposure.

Loss of liquid manure.—The collection and return to the soil of the liquid portion of the manure is evidently the most difficult problem. About one-half of the fertilizing value of barnyard manure is contained in the liquid portion. Storage in cisterns is only partially successful, especially in the Northern States, where the freezing of the liquid during the winter makes its distribution difficult or impossible. On the whole, the most satisfactory method for conserving liquid manure on the farm is to absorb it in the bedding. As much straw, cut or shredded cornstalks, or other refuse material should be used as may be necessary entirely to absorb the liquid. (Ref. No. 4, pp. 160, 161.) Peat or moss, when available, is a far more effective absorbent than straw. The dust from this material, however, makes it objectionable for bedding dairy cattle. Finely ground phosphate rock is often used upon the floors as an absorbent after cleaning the stables. Such use also helps the phosphorus of this material to become available to plants after the manure is applied to the soil and decomposition begins.

Losses from storing manures (Ref. No. 3, pp. 598–602; or No. 4, pp. 175–181).—There are two ways in which fertility is lost from the manure pile while stored. First, by leaching out of much of the soluble and most valuable part, and second, by fermentation and heating, which causes loss of nitrogen in the gaseous form. Leaching should be prevented by having the manure pile either covered or so completely built that no more water is absorbed by the manure than is necessary to keep it in a moist condition. In the South and

other regions of considerable winter rainfall some form of manure shed should be provided. In some localities of the North the winter rainfall may be not more than sufficient to keep the manure properly moist. However, alternate wetting and drying is especially objectionable on account of the large loss of nitrogen it causes. Overheating from fermentation is most likely to occur in horse manure. (Ref. Nos. 1, p. 149; 7, p. 312.) This should if possible be mixed with cow manure, and if not, it should be kept sufficiently moist and compact to prevent overheating, or firefanging. Under the very best care it is practicable to collect and return to the soil about 85 per cent of the plant-food elements contained in the fresh manure. If three-fourths of the food elements taken from the soil by the crops which are fed to animals is voided in the manure, and 85 per cent of this can be returned to the soil, about two-thirds of the fertility contained in crops removed from the land and fed to animals can be returned to the soil in manure. Every effort should be made to make the fraction actually returned as large as possible.

Application of manure to the land (Ref. Nos. 1, pp. 165–172; or 3, pp. 602–609; or 4, pp. 181–186).—On account of the danger of loss of plant-food material from manure undergoing decomposition, it is best to apply it directly to the land as produced. This can usually be done in general farming. Coarse and fresh manure can be used on rank-growing crops such as corn, cabbage, sugar beets, etc., by applying it during the winter as produced to land to be planted to these crops. These crops can then be followed by those to which it is not well to apply manure directly, such as potatoes and other crops affected by fungus diseases which are encouraged by the raw manure. When it is to be applied to sandy soils, however, the manure should be composted, as otherwise the decomposition in the soil of the bedding will dry out the soil too much. Fine or well-rotted manure can also be used to great advantage as a top-dressing on meadow land or on pasture.

It is often thought that pastures do not need fertilization, but this is a great mistake, for since the animals are in the yards or stables part of the time and are storing up the elements of plant food in their bodies, they cause a constant drain on the soil of the pasture which is not made good by the manure dropped in the pasture. This loss must be met by additions either of manure from the stable or of commercial fertilizers.

Few crops will give better returns for manure applied than hay, especially timothy and other true grasses. Clover, alfalfa, and other legumes will respond wonderfully to manure; but since these plants can secure most of their nitrogen from the air, if necessary, they should be made to do so by supplying them with fertilizers containing the other elements only. This will permit the use of all of the manure

of the farm on crops which require the nitrogen as well as the other elements, and so increase the fertility of the whole farm. Manure applied to meadow land should be well composted, so that its fertilizing constituents are largely soluble and will be leached down into the soil at once, and the straw used as bedding will be rotted and will not be raked up with the hay.

As a rule it is better to plow manure under when applied on such crops as corn, cabbage, sugar beets, etc., because then it causes no difficulty in cultivating these crops, as it often does when applied as a top-dressing after the land is plowed. But on heavy clay soils the manure is more effective when applied as a top-dressing and cultivated into the soil, because then it is more readily oxidized than when plowed under. It can be used as a top-dressing in this way if well rotted.

The rate at which the manure should be applied will, of course, be determined in part by the supply produced on the farm. But it is much better to use small quantities frequently than large quantities seldom. Four or five tons to the acre every three years is better than 12 or 15 tons every nine years. The even distribution of manure, such as can be accomplished with the manure spreader, is also a matter of great importance.

GREEN MANURES.

(Ref. No. 7, pp. 348–362; or No. 6, pp. 342–348.)

Decaying vegetable matter in some form is indispensable for keeping a soil in the best physical condition and in the highest state of fertility. If the system of farming is such that not much live stock is fed upon the farm, the manure will not be sufficient to supply the needed amount of vegetable matter to the soil, and some other means should be adopted as a substitute. In such a case, the most practical method is to grow crops to turn back to the soil. Such crops are called green manures.

There are two ways of furnishing green manures: (1) A crop is produced during the regular growing season, but instead of being harvested, it is returned to the soil. This method may be necessary in the North where the growing seasons are short; (2) a crop to return to the soil is grown with the regular harvested crop and left on the ground from the harvest; or a crop is sown after the regular crop is removed and gets its growth during the fall and winter months, in which case it is called a cover crop. This method of green manuring is now much used in the Southern States.

In addition to the value to the soil of vegetable matter supplied, the following benefits come from the green-manure crops: (1) Where a cultivated crop has been grown and harvested, considerable available plant food is left in the soil which may be taken up in the growth

of the cover crop to be given up again from decay in the soil to the succeeding regular crops. Where no cover crop is used, there may be considerable leaching during the fall and winter, especially of the nitrogen compounds. (2) When a cover crop is on land during the heavy rains of fall and winter, the covering and the roots in the soil are very effective in preventing erosion. This is especially true in the case of clay soils. (3) When legumes are grown for green manures, the nitrogen content of the soil is much increased. This important fact should not be overlooked.

The crops most commonly grown for green manuring are: Non-leguminous—rye, wheat, oats, and barley; leguminous—cowpeas, soy beans, crimson clover, red clover, sweet clover, bur clover, Japanese clover, and vetch.

COMMERCIAL FERTILIZERS.

(Ref. No. 7, pp. 449–475.)

Since the time when it became generally accepted that one or more of three essential elements of plant growth, viz, nitrogen, phosphorus, and potassium, are most apt to be found in soils in such small quantities as to limit crop production, there have gradually sprung up commercial enterprises organized for the purpose of manufacturing and distributing materials containing one or more of these so-called essential elements. Usually substances containing two or three of these elements are mixed in different proportions and put upon the market under different names, such as corn grower, cotton grower, potato grower, etc. When materials thus manufactured and sold contain the three essential elements, they are called complete commercial fertilizers. There are hundreds of brands of complete fertilizers upon the market, and the number is fast increasing. Materials commonly used for complete fertilizers are sodium nitrate for nitrogen, acid phosphate for phosphorus, and potassium chlorid (muriate) or potassium sulphate for potassium. In the higher grade, and consequently higher priced, complete fertilizers the materials used are comparatively pure; in the lower and cheaper grade some material called a filler is often used in the mixture. At the present time ground limestone and peat are used to some extent as fillers.

Use of fertilizers in the United States.—The largest part of the fertilizers used is applied to those soils which have been longest under cultivation. This statement is particularly applicable to the Southern States where the sandy soils, the long hot seasons, and especially the single-crop system (culture of cotton, a nonleguminous crop) have very much depleted the humus content and general fertility of the soils. Quoting from the United States Census Report:

In 1909 the farmers of the United States reported the expenditure of $114,882,541 for fertilizers, of which $75,752,296, or 65.9 per cent, was spent by the farmers of the

South. The farmers of the Atlantic division alone spent $59,625,130, or more than half of the total. Most of the expenditure for fertilizers outside of the South was reported from the three northeastern divisions of the country, the New England, Middle Atlantic, and East North Atlantic.

Fertilizer control.—Most of the States have enacted laws to govern the sale of fertilizers. The laws generally require that the containing packages shall show the guaranteed analysis of the materials. The analyses are commonly reported in terms of nitrogen or of ammonia, total and available phosphoric acid, and potash.

Fertilizers containing about 2 per cent ammonia, 8 per cent phosphoric acid, and 2 per cent potash are very commonly found in the market and are often known as 2:8:2 goods. Such fertilizers are considered low grade.

As stated before, nitrogen may be calculated from ammonia by multiplying by 0.82, phosphorus from phosphoric acid by multiplying by 0.4366, and potassium from potash by multiplying by 0.83. Thus 2 per cent of ammonia $\times 0.82 = 1.64$ per cent of nitrogen.

The use of mixed fertilizers.—There are so many different kinds of soils in the United States, so many different crops grown, and so many different conditions to meet, that it is wholly impracticable in this treatise to attempt to give directions with regard to proportion and quantity in the use of mixed fertilizers. The agricultural experiment stations of the different States have conducted soil surveys, soil analyses, and soil-fertility experiments until there is now a considerable fund of information with regard to the best use of fertilizing materials for the types of soil and crops grown in each State, and it is best to apply to one's own experiment station for this information. In general, it is well to decide first how much nitrogen, phosphorus, and potassium should be added to the soil for the crop to be grown; then to compute the quantity of the different compounds of these elements necessary to furnish what is desired; and, finally, to use the materials which will furnish the elements needed in available form at the least cost.

Home mixing of fertilizers.—Of late years farmers are beginning to buy separately the fertilizer materials and to mix these materials themselves as desired. Some of the advantages of this practice are: (1) One can add to the soil at any time any one of the fertilizing elements alone, or any combination of the elements, in the proportions desired. (2) Many grades of complete fertilizers can be made, as needed for different crops and soils, from only three materials. (3) The buying and application of the fertilizers can be done more intelligently, and often more cheaply. (Read pp. 476–490, Ref. No. 7.)

EXERCISES, LESSON VIII.

Materials required.—A pint of muck or peat; two wide-mouthed pickle bottles; three or four ounces of ammonium carbonate; two pieces of woolen cloth for strainers; two glass tumblers.

1. *Why barnyard water is colored.*—Every farmer and farm boy has observed the peculiar color of barnyard water and has detected strong ammonia odors in the horse stable. The one condition is closely related to the other in this way: The nitrogen of an animal body is excreted through the urine. The principal nitrogenous substance in urine is urea. Urea is acted upon by fermenting organisms producing the compound ammonium carbonate which, with moisture, has the ability to dissolve organic matter. This accounts in a large degree for the brownish color of barnyard water. This solvent action may be observed as follows:

Place a handful of peat or muck in each of two wide-mouthed pickle bottles. Add about half a cup of ammonium-carbonate solution to one, and a like amount of water to the other. Shake each for a few minutes, let stand about 20 minutes, then shake again for a few seconds. Run the liquid contents of each bottle through woolen cloth into glass tumblers and note color of liquids. Explain results.

PROBLEMS.

1. A ton of good average barnyard manure contains about 0.5 per cent nitrogen, 0.1 per cent phosphorus, and 0.4 per cent potassium. How many pounds of each of the elements are contained in 1 ton?

2. When nitrogen is worth 18½ cents per pound, phosphorus 10 cents, and potassium 6 cents per pound, what is the value of the plant food contained in 1 ton of good manure?

3. A farmer applied 30 tons of good manure per acre to his tobacco land. About how many pounds of each of the fertilizing elements did he apply per acre in the manure? What may be considered the total value of the plant food applied?

4. How many pounds of each of the three fertilizing elements are applied when 8 tons of manure are applied per acre? What is the value of these fertilizing elements?

Under average good conditions about 40 per cent of the nitrogen is lost in the feeding transaction and production and handling of manure, about 20 per cent of the phosphorus, and about 5 per cent of the potassium (straw for bedding).

5. A 40-bushel barley crop removes from the soil about 48 pounds of nitrogen, 9 pounds of phosphorus, and 30 pounds of potassium. If 10 acres of such barley were fed and all the manure produced from this crop were returned to the same field, would there be a loss or gain, and how much of nitrogen, phosphorus, and potassium as compared with that contained in the soil before the crop was planted?

6. The amount of plant food removed per acre by corn, oats, and alfalfa is as follows:

Amount of plant food removed from the soil by different crops.

Crop.	Yield per acre.	Pounds per acre removed from soil.		
		Nitrogen.	Phosphorus.	Potassium.
Corn, bushels	65	85	14	79
Oats, bushels	50	50	8	37.5
Alfalfa, tons	4	200	18	95.5

How much plant food would be lost in feeding 7 acres of corn averaging 65 bushels of shelled corn per acre, and 10 acres of oats, averaging 50 bushels per acre? (All straw used for bedding.)

(*a*) The nitrogen contained in the alfalfa crop may be considered the amount fixed from the air by that crop. How much nitrogen would be added to the soil if the manure produced from feeding 2 acres of alfalfa hay averaging 6 tons per acre were returned to the same field? Would there be a loss or gain of phosphorus, and how much?

(*b*) A man fed 20 acres of corn yielding 65 bushels of shelled corn per acre, 10 acres of oats yielding 50 bushels, and 5 acres of alfalfa hay yielding 5 tons per acre. All manure produced was used on the farm. What was the loss or gain of nitrogen in the feeding transaction?

(*c*) If 5 tons of cottonseed meal were fed during the time required to feed the crops in the preceding problem, what would be the loss or gain of nitrogen and phosphorus to the soil? One ton of cottonseed meal contains about 135 pounds of nitrogen and 25 pounds of phosphorus.

7. At the Hatch experiment station, Massachusetts, it was found that the drainage from the gutter behind milch cows contained 0.98 per cent nitrogen, 0.1 per cent phosphorus, and 0.73 per cent potassium. How many pounds of each of these elements were contained in a ton of this liquid?

(*a*) At the same station it was found that the liquid drained from a manure heap contained 1.5 per cent nitrogen, 0.043 per cent phosphorus, and 4.06 per cent potassium. Compare the fertility contained in 1 ton of this liquid with that in problem 7. What conclusions are to be drawn from these figures?

REVIEW QUESTIONS, LESSON X.

1. Name some of the factors which influence the amount of plant-food material that may be recovered in the manure produced from feeding.
2. In what form is most of the nitrogen voided from the animal body?
3. Compare the amount of phosphorus retained in milk with that retained in meat.
4. About what part of the nitrogen and phosphorus in feeds fed is recovered in the manure?
5. About what part of the plant food contained in feeds is returned to the soil?
6. How may the loss of the liquid manure be reduced to a minimum?
7. Explain how losses of plant food from manure occur.
8. Discuss the time and method of applying manure.
9. Discuss the condition manure should be in when applied to certain crops and soils.
10. How much plant food is contained in 1 ton of average manure, and what is its value?
11. What is a green manure? Under what conditions is it necessary to use green manures to retain or to increase the fertility of a soil?
12. What crops are best to use for green manuring?
13. What is a cover crop? Of what value are cover crops to the soil besides their manurial value?
14. What is a complete commercial fertilizer?
15. Is it better to use fertilizers of high or low grade? Why?
16. Discuss home mixing of fertilizers.

LESSON IX. SOIL ACIDITY AND LIMING.

(Ref. No. 1, pp. 242–248; or No. 5, pp. 160–164; or No. 6, pp. 313–319.)

A condition of the soil which effects important changes, including nitrification and nitrogen fixation, is that of acidity. Practically all soils formed in regions of moderately heavy rainfall and not

derived by glaciation from limestone rocks are found to be more or less acid. Liming is the only practical way for correcting acidity. It is also beneficial to the soil in several other ways. Nearly all of the vast area of sandy lands of the South, and much land of the North and Northeast, as well, need liming. Besides other related topics, there will be taken up in this lesson the means for detecting soil acidity, together with the different kinds of lime, the quantity of each to be used on the soil, and the methods of application.

Lime is not generally considered as a fertilizer, although calcium, the mineral element of lime, is present in certain soils to such a limited extent that some substance containing this element needs to be added as a plant food.

Reasons for soil acidity.—While the question of acidity is still under investigation, the following reasons for this condition in soils seem to be fairly well established: (1) The abnormal breaking down of large quantities of vegetable matter in lowlands poorly drained causes acidity. (2) Because of the greater water solubility of the basic compounds of the soil than of the acid silicates, the bases are removed more rapidly from leaching than are the acid compounds. Since cultivated areas leach more readily than wooded and pasture lands, they thus develop acidity more rapidly. (3) In cropping, the basic elements of plant food are taken more rapidly from the soil than are the acid elements. When crops are removed from the land, therefore, instead of being fed and the manures returned, an acid condition eventually results from this cause. Moreover, the basic elements are carried from the subsoil to the surface to some extent by the roots of plants, and it is a common experience to find the subsoil acid when the surface is still neutral or alkaline. (4) An acid residue is left in the soil from some fertilizers. Ammonium sulphate, for example, when applied to the soil gives up ammonia as a plant food and leaves sulphuric acid as a residue. It is thought, likewise, that when potassium sulphate is used in fertilizers, a part of the potassium becomes liberated, leaving an acid salt of potassium in the soil.

Objections to acidity (Ref. No. 7, p. 141).—Nitrification of organic matter does not take place readily in acid soils, although in the case of acid marsh soils which are well drained, the nitrification may be sufficient to supply nitrates for the rapid growth of most crops. Acidity in the soil, moreover, has much more detrimental effects in its influence on nitrogen fixation by certain tubercle-forming organisms than on the process of nitrification. The bacteria which form tubercles on medium red clover, alfalfa, sweet clover, soy beans, and some other legumes do not develop at all rapidly in acid soils, and when the soils are quite acid it is necessary to use lime to correct

the acidity in order to secure a good growth of these plants. Some other legumes, such as yellow lupine, serradella, and cowpeas are usually able to grow well on distinctly acid soils, though in some cases even these plants seem to be benefited by lime. The beneficial effect of lime on alfalfa and the other first-mentioned crops is in changing the reaction of the soil from acid to neutral or alkaline, while the benefit occasionally reported in the case of serradella and lupine is possibly due to the fact that on certain soils these plants do not find sufficient calcium for their growth, and the lime supplies this element.

Detection of acidity (Ref. No. 1, p. 247).—The presence of acidity may be detected in various ways. Perhaps the simplest method is by the use of litmus paper. This is cheap and can be purchased at any drug store. A strip of blue litmus paper is placed in the bottom of a drinking glass and covered with white blotting paper or filter paper on which the soil to be tested is placed. Clean rain water is added slowly until the soil and the litmus paper become damp. If the paper turns distinctly pink it shows that the soil is acid. It may be well to wait for ten minutes or more before coming to a final decision. The degree of acidity is roughly indicated by the rate at which the change in color takes place and its final intensity. Red litmus paper turns blue in the presence of alkalinity. It will often add to the interest and value of the test if strips of both red and blue litmus paper are placed in the bottom of the glass.

A method of determining the presence of limestone and the consequent absence of acidity is to drop dilute muriatic acid upon moist soil. Any perceptible bubbling, or effervescence, indicates the presence of lime. The character of this effervescence may easily be learned by dropping some of the acid upon a piece of limestone or marble, or into a little baking soda dissolved in water. The presence of lime in the subsoil may sometimes be shown by this test when the surface gives no positive test. A failure to detect the presence of limestone by this test should not be interpreted as proof of acidity in the soil.

The best indication of the need for lime is the type of plant growth that the soil bears. Where alfalfa, red clover, and sweet clover grow vigorously no lime is needed. The predominance of sorrel, broom sedge, white daisy, or redtop indicates a need for lime.

Correction of acidity (Ref. No. 7, pp. 382–390; or No. 6, pp. 303–313).—The practical means for correcting the acidity of soils are (1) drainage, where needed, and (2) the application of lime in some form. Lime suitable for use in correcting soil acidity may be in any one of three forms. The first is the carbonate; second, burned or quicklime; and third, water-slaked or hydrated lime. These forms

of lime are different compounds of the element calcium, and any one of them will neutralize the acidity of soils. The carbonate occurs in different forms, among which are limestones, marl, chalk, shells of mussels, and refuse lime from sugar-beet factories. (Ref. No. 5, pp. 160–182.) Any of these forms of calcium carbonate when ground sufficiently fine are well adapted for use in correcting soil acidity. Not only does this form of lime have a good effect upon the soil, but it is relatively convenient to handle. Whenever it can be applied at a reasonable price as compared with other forms of lime it should generally be used.

Quicklime, sometimes called lump lime, results from the burning of limestone. In the process of burning carbon dioxid is driven from the limestone as a gas, leaving the quicklime, chemically, calcium oxid, in lump form. Quicklime, like the forms of calcium carbonate, should be finely divided before it is mixed into the soil. This form of lime is caustic and disagreeable to handle.

Water-slaked or hydrated lime results from adding water to quicklime. This process produces a great deal of heat and causes a chemical reaction which results in the formation of calcium hydroxid. Hydrated lime is finely pulverized and, from this standpoint, is in good condition to apply to the soil. Quicklime is sometimes spread without grinding or slaking, and, if done during a rainy season, will soon become slaked by the water which falls upon it. In this case it is advisable to spread it more thoroughly by harrowing before working it into the soil.

Slaked lime, like quicklime, is caustic. It is not advisable to use these forms in excessive quantities, particularly on light soils deficient in organic matter, since they unduly hasten the breaking down of the vegetable matter of the soil. This process is accompanied by an increased formation of nitrates, which may be obvious in growing plants, but with a corresponding depletion of the soil, especially if the growing crop is nonleguminous. Caustic lime gradually unites with carbon dioxid and is thus converted into the carbonate. When heavy applications of caustic lime are mixed with sandy soils, a cementing of the sand grains sometimes takes place, causing a detrimental clodding condition. On the other hand, liberal applications of caustic lime produce a flocculating effect upon clay soils, which reduces clods and improves soils physically.

No harm can come to the soil from the use of any form of calcium carbonate, even in large applications, but it should be noted that large quantities of lime in any form are favorable to the scab of potatoes. The form and quantity of lime to use is a practical question depending primarily on the degree of acidity of the soil and the relative cost of available materials. The cost depends on grade of

material, original cost, fineness, freight, distance to haul, condition of roads, and handling.

When 100 pounds of pure limestone is burned it gives 56 pounds of quicklime, which, when slaked with water, will give 74 pounds of hydrated lime. Hence, for neutralizing acidity, 56 pounds of burned lime is equal to 100 pounds of limestone or 74 pounds of slaked lime. Relatively speaking, the application of 1 ton per acre of burned lime would be equivalent to the use of $1\frac{1}{2}$ tons per acre of slaked lime, or 2 tons per acre of finely ground limestone. On average acid soils such an application is ample for from three to five years, at the end of which time it might be advisable to use one-half the amount of the previous application. When limestone is used it should be comparatively fine, and it might prove in many cases more practical, and eventually more economical, to apply a larger quantity per acre than above noted at correspondingly longer periods of time. Where lime in any form is used for alfalfa, which commonly occupies the land from six to eight years, liberal applications are necessary. In a short rotation, where potatoes is one of the crops, it is advisable to make light applications of lime and to add the material during each cycle of the rotation following the harvest of the potato crop.

Lime may be applied at any season of the year when its use is convenient. It should be mixed with the soil as thoroughly as possible. For this reason it is better not to plow the lime under, but to apply it after plowing, following with the disk or other harrow. If applied just ahead of a tilled crop, such as corn, the cultivation of the crop will aid in mixing the lime into the soil. In a distinctly acid soil, where red clover is one crop of the rotation, it is well to apply the lime in preparing for the crop preceding the red clover. Surface application on grass land will give some benefit, but not so much as where the lime can be more thoroughly incorporated with the soil.

The application of lime by hand with a shovel is tedious, and it can not be spread very evenly in this manner. The fertilizer attachment of a grain drill will sow lime when it is granular and not damp, but will spread not more than one-half ton to the acre. It is a common practice to use a manure spreader for this purpose, placing a layer of litter upon the table before loading the lime. Moreover, where the use of some form of lime is an established practice on the farm, a lime distributer will prove a good investment. There are several kinds of these on the market. Satisfactory homemade distributers have been built by using the wheels from a laid-by mowing machine and constructing a box and the feeding apparatus.

Other benefits from the use of lime.—Besides correcting acidity, lime causes other benefits in the soil, the principal of which are (1) the improvement of the physical condition, especially of clays; (2) the im-

provement of the soil for the work of nitrifying bacteria; and (3) an increase in the beneficial results from potassium salts and phosphates. While there may still be some question as to the exact chemical changes in the soil from the use of lime, experimental work at different stations has now quite clearly proved beneficial results to the extent of profit from the use of lime with potassium salts, phosphates, or manures over the use of any of these alone. The extent of these benefits, of course, varies with the type of soil.

EXERCISES, LESSON IX.

SOIL ACIDITY AND LIMING.

Materials required.—Two long pickle bottles; a small quantity of clay soil; soft water; limewater; a bottle of dilute muriatic acid; some powdered limestone, marble dust, old wood ashes, coal ashes, air-slaked lime, baking soda, and quicklime; blue and red litmus paper; some common salt; a few sweet apples; a bar of soap; vinegar and sugar; samples of soil from the community; a few old cups and saucers.

The flocculating effect of lime on heavy clay (Ref. Nos. 1, p. 243; 4, p. 228; 7, p. 379).—In each of two long, clean pickle bottles put a teaspoonful of fine clay soil. Fill both bottles within 2 inches of the top with soft water. Into one bottle pour about three tablespoonfuls of limewater. Shake both thoroughly for two or three minutes and note the formation of floccules in the bottle containing the limewater. Set the bottles aside and note the comparative rate of clearing by settling. What is meant by soil flocculation? How does limewater aid in clearing the turbid water?

Simple chemical test for carbonates.—Effervescence occurs when muriatic acid comes in contact with carbonates. This is a simple chemical test by which carbonates may be determined.

(a) Place a quarter of a teaspoonful of powdered limestone in an old cup or saucer, pour on about a tablespoonful of dilute muriatic acid, and note results. What causes the bubbling or effervescence?

Apply this test to the following substances: Marble dust, wood ashes (old), coal ashes, air-slaked lime, baking soda, and fresh quicklime. What kind of gas is chemically combined in all carbonates? How does this gas differ from that given off by our lungs? What kinds of carbonates do most limestones contain? Baking soda?

THE USE OF LITMUS PAPER.

(Ref. No. 9, pp. 41–57.)

Litmus paper may be used to determine the reaction of liquids.—(a) Dip a small piece of blue litmus paper into an acid solution. What happens? Try a piece of red litmus paper. Any reaction? Acid turns blue litmus paper red.

(b) Dip a piece of blue litmus paper into an alkaline solution. Any reaction? Test with a piece of red litmus paper. What change takes place?

An alkaline solution turns red litmus paper blue. An alkaline solution is the opposite in reaction to an acid solution.

(c) Determine the reaction that pure water has on blue and red litmus paper.

Water is a neutral liquid, neither acid nor alkaline.

(d) By the use of blue and red litmus paper determine the reaction of the following solutions: A common salt solution, sweet apple juice, soapy water, and vinegar solution sweetened with sugar.

Litmus-paper test for acid soils.—Since an acid solution will turn blue litmus paper red, we can tell by use of blue litmus paper whether or not a soil is quite acid.

(a) Place about three tablespoonfuls of soil in a clean dish and moisten to a thick mud with clean, soft water. With a clean stick separate the mud into two portions and lay on one portion a piece of blue litmus paper. Press the other portion of wet soil down on the litmus paper; leave for five minutes, then carefully remove the upper portion of the soil and examine the paper. If it has turned pink or pink spots appear upon it the soil is acid.

(b) Place one piece each of red and blue litmus paper in the bottom of a drinking glass. Over this place white blotting paper or filter paper, upon which put three or four tablespoonfuls of soil. Now add clean rainwater slowly until the paper becomes damp. After 10 or 15 minutes note whether a change has occurred in the color of the litmus paper. If the blue litmus paper has changed to a pink color, the soil is acid.

Compare this test with (a) to determine which method is preferable.

(c) Repeat test (a) or (b) on other soils. Save one of the acid soils for the next exercise.

Lime is used to correct acidity in soils (Ref. No. 1, p. 251).—Place about three tablespoonfuls of acid soil in a clean dish and thoroughly mix with it about a quarter of a teasponful of air-slaked lime. Moisten the mixture and test with blue litmus paper as before. What effect did the lime have on the acid soil?

REVIEW QUESTIONS, LESSON IX.

1. How can acidity in soils be detected?
2. What are the objections to soil acidity?
3. Name some legumes that can tolerate soil acidity.
4. Describe lime carbonate, quicklime, and water-slaked lime.
5. Explain how lime neutralizes acids in soils.
6. Why is it undesirable to use quicklime in excessive quantities on light, sandy soils?
7. Discuss the relation of the fineness of pulverized limestone to the rate of application.
8. Describe three ways in which the application of ground limestone to a very poor acid clay soil may be of benefit.
9. When a soil is neutral or alkaline in reaction, what may be implied?
10. What becomes of the lime supply of soils?

LESSON X. MANAGEMENT OF SPECIAL SOILS.

The successful management of any soil depends on an understanding of its special characteristics. Its weak points must be recognized and corrected if possible, and crops which are best adapted to the soil should generally be grown. Among the soils which require special management are the sands, the clays, and marsh lands.

SANDY SOILS.

Sandy soils are low in water-holding capacity, are subject to being blown by the wind, and are low in elements of plant food.

Moisture of sandy soils.—Low water-holding capacity of sandy soil has been explained in discussing the relation of texture to the amount of moisture soils can retain. Moreover, small differences in the texture of sandy soils or the influence of small quantities of organic matter considerably increase the total amount of water held

during a season. This is because the additional quantity of water which the soil having the finer texture or the larger proportion of organic matter may hold is repeated after each succeeding rain, so that if showers come eight or ten times during a season and are followed by dry periods, the total quantity of water available to crops under the first-named condition is considerably larger than under the second. The capillary rise of water is comparatively fast in sandy soil, but it can not be raised from any great depth. The moisture of sandy soils which is retained by capillarity is more effectively used by the growing crop, however, than in the case of soils of finer texture. (Ref. No. 2, p. 161.) Besides, the portion of the rain falling as light or moderate showers after dry periods is more largely available to crops growing on sandy than on heavy soils. A rainfall of one-quarter inch will penetrate the sandy soils several inches and so reach the roots of the growing crop, while this amount of rain falling on a soil of fine texture will be absorbed and held so near the surface that it does not affect the roots of the plants, and practically all of it evaporates from the surface soon after the rainfall. The control of soil moisture in sandy soils can be effected by the methods discussed under prevention of evaporation, page 28. Rolling these soils after seeds have been planted has the effect of increasing the movement of the water to the seed bed, but the field must be dragged after the rolling to prevent the evaporation of water from the surface. It is desirable to plant seed more deeply in sandy soils than in heavier or clay loam soil. Clover, or other small seed, should be sown an inch or an inch and one-half deep, so that it will have sufficient moisture for germination.

The topography, or "lay of the land," and the distance to the ground water of sandy soils is a matter of considerable importance. Owing to the freedom with which the water of the saturated portion of the subsoil can move in sandy soils, the ground water table is usually quite level and does not rise as rapidly under hills of sandy soils as it does in hills of heavier soils. For this reason the upper portions of hills of sandy soils are usually so far above tbe ground water table that practically no water is drawn from the subsoil. On the other hand, when sandy soils are level or have only a very small slope, and the ground water table is 6 or 8 feet below the surface, a considerable amount of moisture may be drawn up far enough to reach the roots of growing crops.

Wind blowing of sand.—In addition to danger from smothering by drifting soil, crops growing on sandy soils are often very seriously injured by the cutting action of sand blown against them. Not infrequently a single sand storm of a few hours' duration coming in spring or early summer will do as much damage as a severe frost.

These windstorms usually do not have much chance to develop during the summer when the ground is more fully covered by growing crops. To prevent this danger of wind-blown sand the ground should be kept covered with growing crops as much as possible. Land on which potatoes have been grown may be seeded to rye at once after the digging of the potatoes, and, if desired, clover may be sown on the rye early in the following spring. In this way the ground is never exposed for any length of time to the wind. Fields on sandy farms should also be laid out in long narrow strips, so that the ground on which the tilled crop, such as corn or potatoes, is planted will alternate with strips bearing grain or grass which protects the ground.

Fertility (Ref. No. 7, p. 415).—Sandy soils are low in the total amount of plant food they contain, and often what they do have is rather unavailable because of the coarseness of the grains of which it consists. It is particularly desirable that the organic matter of such soils be increased, partly because by so doing the nitrogen can be best increased, and partly because the organic matter acts on the mineral matter in the soil so as to make it available for growing crops. For adding organic matter legumes should be used as far as possible, since they have the power of gathering nitrogen from the air. In the growing of these legumes, such as clover, soy beans, etc., the use of a fertilizer containing potassium and phosphorus is important. Lime is also often needed to secure satisfactory crops of alfalfa or clover. These plants can secure much of their nitrogen from the atmosphere, but they require the mineral elements from the soil just as all plants do. However, it is important to notice that in the decomposition of organic matter produced by the growing and plowing under of legume crops the phosphorus and potassium which was used in their growth become available to succeeding crops, and this further increases the value of legumes as fertilizers.

Crops for sandy soils.—The readiness with which sandy soils may be worked, even immediately following rains, especially adapts such soils to the growth of crops requiring considerable manual labor, such as vegetables and small fruits. The advantage which sandy soils have in this respect is so great that it offsets their low fertility and makes it preferable to use them for such purposes, even though fertilizers must be purchased in larger quantities than would be necessary on heavier soils. The low water-holding power of such soil also permits it to become warm much more quickly in the spring than heavier soils which contain much water, the evaporation of which keeps them cold. This higher temperature of sandy soils adapts them to certain crops requiring a high temperature, such as melons, tomatoes, and potatoes. The fact that sandy soils are subject to drought during periods of small rainfall in the summer makes them poorly suited to grass crops, which should grow all the season, especially when used

for pasture. This seriously lessens their value for such crops as sugar beets, cotton, or corn, which grow through the whole summer. On the other hand, some small grains, which make their growth very early in the season, are better adapted to such land. Crop rotation for light soil should be short. Many of the best rotations are of but three years' duration.

Live-stock farming on sand.—The use of pasture is still, and probably will long remain, an important factor in most lines of live-stock farming. This is partly because in grazing, stock harvest their own feed, and in this way greatly lessen the expense for labor. Since sandy soils, as we have seen, are poorly adapted to pasture grasses, they are not as well suited to most lines of live-stock raising as are heavier soils. However, it is frequently the case that considerable quantities of produce, grown in connection with truck raising on sandy soils, are not marketable and should be fed to some form of live stock. A small number of live stock, therefore, should usually be kept, even on sandy farms, the principal business of which is the growing of truck or vegetable crops.

CLAY SOILS.

Formation and location.—Clay soils are commonly formed by the settling out of fine sediment in standing bodies of water into which streams carrying the sediment have run. Such areas of standing water occur as lagoons along main river valleys like those of the Mississippi, Ohio, Missouri, and other large rivers. They were also formed in extensions of the Great Lakes which existed toward the close of the glacial period. Broad belts of extremely heavy clay soils were formed in this way along the southern shore of Lake Superior, along Lake Michigan in Wisconsin, and on the southern borders of Lake Erie and Lake Ontario. Many shallow lakes existed for a comparatively short time at the close of the glacial period. In these great areas heavy clay soils were formed. Lake Agassiz in Minnesota, North Dakota, and Manitoba (long since dried up) is one of the best illustrations of the formation of heavy clay soils. The clay soil of the Champlain Valley in New York has its origin in the same way. Some areas of heavy clay soil have also been formed along the seashore as deltas and in bodies of salt water formed by shutting off the main portion of the ocean. As stated in Lesson I, a residual soil from limestone is also an extremely fine clay. This is because the soil is made up of the insoluble portions of the rock, the soluble portions having been dissolved and carried away by percolating water.

Characteristics of clay soils (Ref. No. 7, pp. 95–99).—Clay soils owe their special character largely to their very fine texture. Their large water-holding capacity and poor underdrainage is the immediate result of this texture. As a secondary result they often have poor tilth and are liable under certain conditions to be cold during the

spring. They usually have a high content of potassium, and the phosphorus content is sometimes large. Their treatment, therefore, must be such as to overcome their peculiar difficulties and take advantage of their particularly strong points.

Drainage.—Since large portions of these heavy clay soils were formed as deposits in standing bodies of water, they very commonly have comparatively level surfaces. They therefore frequently have poor surface drainage as well as poor underdrainage. For general farming everything possible must be done to secure good surface drainage when the expense of tile is unwarranted. Tile drainage, however, is often necessary in order to permit the use of such land for crops requiring considerable tillage. This form of drainage for such land is usually profitable, even for staple crops. The expense, of course, varies, depending on the distance to an outlet, the presence of stones in the subsoil, and other factors. Ordinarily the expense is between $20 and $30 per acre. Since a tile system once carefully installed in clay soil will last almost indefinitely, the expense to be charged to the land is simply that of the interest on the investment, or from $1.50 to $2 per year. Indeed, the entire expense is very commonly recovered by the increase of crops in from one to three years.

Tilth.—The most serious difficulty in the management of heavy clay soils results from their poor tilth. Such soils are apt to bake and form large clods, so that preparation of a good seed bed and the cultivation of the crop is difficult and involves much extra labor. This poor tilth is due to the fact that the films of water surrounding the fine grains draw the particles so closely together when they dry that they are held with considerable tenacity. This difficulty may be overcome to a limited extent by increasing the amount of organic matter. Humus and vegetable matter in such soils has the effect of lessening the tendency to form clods. Thus, after a heavy clay soil has grown a crop of clover, or has been in grass for some time, it is easier to retain a good tilth than if it is kept in tilled crops continually. As before shown, liming of clays, especially with quicklime, produces a flocculating effect upon the soil and so reduces the tendency to clodding and greatly improves its tilth. Another extremely important factor is the moisture condition when they are cultivated. As before stated, when such soils are plowed or otherwise worked in a wet condition, they have a marked tendency to puddle and run together in such a way that very hard and resistant clods are formed. It is extremely important to do all the work of tillage on such land when the soil is in just the right condition of moisture, so that the clods will break down in the soil. This condition must be determined for each individual field and with a little practice can readily be recognized. Plowing clay land in the fall and

leaving it in the rough plowed form gives frost and weather an opportunity to break down the clods, causing them to crumble. Care must be taken not to attempt to work the land in the spring until the surface is dried off enough to permit harrowing or disking without causing puddling.

Crops for clay soil.—On account of their fine texture and the difficulty with which roots penetrate clay soils they are not well adapted to such crops as have coarse roots, which can not readily enter the soil. On the other hand, extremely fine roots of grass are able to find their way into the most dense clays and can therefore take advantage of the large water-holding capacity such soils possess. Small grains, such as barley and wheat, do well on these soils for the same reason. Vegetable and truck crops are, as a rule, very poorly adapted to heavy soils, because their roots usually find difficulty in penetrating the soil, especially in a climate characterized by frequent summer rains. This soil is particularly objectionable for the growing of potatoes, since it is very difficult to prevent the soil from baking and cracking after cultivation has stopped, thus permitting the sun to strike the tubers and cause sun scald. When all of these factors are taken into consideration, it is evident that such lands are best adapted to the growing of cereals, corn, alfalfa, clover, and grass, and that stock raising in which the grass is used for pasture is especially adapted to them.

Fertilizers.—Clay soils vary a great deal in chemical composition. This applies to practically all elements of plant food. Since potassium is almost always present in relatively large amounts, it is often unnecessary to add potash fertilizers. The phosphorus content, on the other hand, is frequently found to be comparatively low, as in the case of the heavy clay soils occurring in the Lake Superior and Lake Michigan region. Besides such soils frequently contain considerable iron, which tends to reduce the availability of the phosphorus. For this reason, and because heavy clays warm up rather slowly and vegetation is apt to be slow and backward, particularly in the spring, a good supply of this element in available form is desirable in such soils. The element phosphorus has a very marked effect in hastening the maturity of practically all crops, so that it is often possible by the use of moderate applications of phosphate fertilizer on cold soils to cause crops to mature from one to two weeks earlier than they would otherwise do. The amount of nitrogen in such soils is extremely variable. In many cases a considerable supply of organic matter containing this element occurs in clay soils as a result of their more or less marshy condition before drainage. This condition permitted the growth of considerable native vegetation, but lessened its decomposition. Soils of this character are usually found well supplied with nitrogen after drainage and cultivation. It often happens, however,

that a considerable part of this black humus is of a very resistant character, and after the more decomposable portion has been used up by a few years' cropping, the nitrogen does not become available rapidly enough to supply the needs of growing crops. Under these conditions nitrogen must be supplied by the growing of legumes, the use of barnyard manure, or in some other way. The amount of lime occurring in these soils is also quite variable. As a rule, soils which were formed in standing bodies of water contain a fair amount of this material, secreted by shell animals and deposited as the clay formed, and also derived from streams running into such bodies of water, which very commonly carry more or less lime. Nevertheless, clay soils of this character are often found which are very low in lime carbonate, or are even acid, so that lime must be used.

Erosion (Ref. No. 2, pp. 50–54; 3, p. 14).—The erosion of soil is a cause of much loss of fertility, and on hillsides, especially of clay soils, it often nearly ruins the fields eroded. Sandy soils are not so readily eroded as clay, because the coarser texture permits the water, except in beating rains or on frozen ground, to pass down into the soil instead of running off the surface. The most practical means of lessening or preventing erosion are: (1) Keeping a high content of decaying vegetable matter in the soil, (2) the maintenance of a grass sod where practicable, (3) the use of channels having a slight grade, keeping grass growing in the bottom where possible, (4) subdrainage, and (5) terracing. A high content of decaying vegetable matter in clay soils causes a texture of increased water-holding capacity, and thus less water will have to run off the surface. Land which is so steep as to give trouble from erosion should be kept in grass as much as possible. It is often possible to grow one intertilled crop on hillsides without danger so as to permit of a rotation, though a second or third year in succession of tilled crops would be followed by serious difficulty. Hillsides should sometimes be laid out in narrow plow lands along the slope and carefully planned so that the dead furrows when cleaned out may be used as channels with very slight fall to conduct the water along the hillside to well-grassed or otherwise well-protected main ditches extending up and down the slope. Deep plowing, which will increase the amount of water a soil may hold from a heavy shower, will lessen the amount which must run off the surface and consequently lessen erosion. The same principle may be still further followed by placing tile for subsurface drainage on springy hillsides, the soil of which would otherwise be kept saturated so near the surface that the water from rain must run off the surface, thus causing erosion. The extreme method of preventing erosion is through the use of terraces, which are sometimes necessary on steep sidehills, especially in the South and other sections where the rainfall is very heavy.

MARSH SOILS.

(Ref. No. 2, pp. 64–68.)

Marsh soils are those which are naturally wet most of the year and contain moderate or large quantities of organic or vegetable matter. Such soils are formed in marshes occurring along the valleys of the larger rivers, along seashores where they are known as tidal marshes, and generally throughout the area which was covered by the last glacial ice sheets, where they were caused by the gradual drying up of hundreds of shallow lakes and ponds. (Ref. No. 3, pp. 41–43.)

Composition.—Marsh soils vary greatly in chemical composition, especially in the amount of organic matter they contain. (Ref. No. 7, pp. 123–125.) It is customary to speak of those which contain moderate quantities of vegetable matter together with considerable quantities of soil and earthy matter as mucks, while those which consist largely of organic matter are called peats. As a rule, soils which would be termed mucks contain from 15 to 50 per cent of vegetable matter, while those which would be called peats always contain over 50 per cent and usually from 70 to 75 per cent of vegetable matter.

Drainage.—It is self-evident that the first need in the improvement of marsh lands is drainage. This has been briefly discussed in the chapter on that subject. In many cases the construction of good open ditches and surface drains is all that is necessary to permit cultivation of marshlands, but these must be made of large size. They should also be given sufficient depth to produce as much underdrainage as possible. Ditches from 6 to 8 feet in depth will drain land for a considerable distance on either side as well as carry very large volumes of flood water. It is important that such a ditch be given the proper cross section; that is, it must not be so wide at the bottom that the small stream of the drier portion of the year will shift back and forth over it, causing it to fill up. A narrow bottom will confine the smaller stream and cause it to keep the ditch clean. The slopes of the sides of the ditch should not be so steep that it will tend to cave in, and they should be grassed as far as possible. However, tile drainage is frequently necessary to permit the maximum use of marshlands. When peaty soils are to be tile drained it is frequently best to put in ditches where the tile lines are to be laid and allow the soil to settle for two or three years before the tiles are placed. If the ditches are then thoroughly cleaned out and the bottom lined, the tile can be placed and covered. In this way a line of tile will be much less apt to be distorted by irregular settling.

Fertility.—Marsh soils have certain marked peculiarities in regard to fertility. Their high content of organic matter, of course, always

means the presence of a large supply of nitrogen. This is usually so great that practically no attention need be given to this element, but it occasionally happens that acid marsh soils are so cold on account of their wetness that nitrification takes place with extreme slowness and there is not a sufficient supply of this element made available. Under such conditions the use of some form of lime to correct the acidity and hasten nitrification is very beneficial. This is discussed on page 62. Manure is often beneficial to marsh soils and should be applied when practicable. (See Ref. 3, p. 613.)

The most marked weakness of marsh soils is with respect to the chemical elements, phosphorus and potassium. While, of course, all of the vegetation which causes the accumulation of organic matter in the marsh contained potassium when it was growing, this element is often leached out of such soils as they accumulate to such an extent that there is not left sufficient to supply the needs of growing crops. For this reason barnyard manure or some commercial fertilizer containing potassium must be used. It is frequently found that marshlands give fair yields for a few years after reclamation before this marked need of potassium develops. This is because some of the vegetable matter most recently formed still contains considerable potassium, and this becomes available through its active decomposition. As a rule, however, fertilizers containing this element must be used on such lands within a few years after their reclamation. The phosphorus needs of marsh soils are quite variable. Marshes which were formed in regions containing considerable limestone, and especially in regions of glacial soils formed from limestone, usually contain a considerable quantity of phosphorus which was deposited in them from surrounding highlands and which becomes available to growing crops. It is often found, therefore, that marshes of this character are not acid and do not show a marked need of phosphorus fertilizers for some years after their reclamation and cultivation. Practically all other marsh soils do require phosphate fertilizers just as much as potassium. The large amount of organic matter in marsh soils may make profitable the use of raw rock phosphate with ordinary field crops. This cheap form of phosphate fertilizer therefore is often preferable to more expensive forms for use on such land.

On account of the unbalanced fertility conditions of these soils, it is usually much more economical, when farms contain upland as well as marshland, to use the barnyard manure produced on the farm on the upland soil, which requires the nitrogen which it contains as well as the other elements, and to purchase commercial fertilizers containing potassium and phosphorus for the marsh soils.

Physical management.—Marsh soils are usually very loose and light in structure, so that growing crops do not find a good foothold

in them and do not come in contact with a sufficient amount of the soil to supply their needs. This is particularly true when fine-rooted crops are to be grown. The use of heavy rollers to firm such soil results in great improvement in this respect. Not only does the rolling and firming of the soil have the effect of bringing the roots in direct contact with a much larger area of soil surface, but it permits a more rapid conduction of the heat from the surface downward. In this way the lower layers of the soil are warmed, and this greatly increases the growth of the roots and promotes bacterial changes, such as nitrification, to which the fertility of the soil is in part due.

Crops for marsh soils.—A great variety of crops have been grown on marsh soils on account of their large supply of nitrogen. They are especially adapted to crops which produce rank growth and require large quantities of this element, such as corn, cabbage, rape, turnips, beets, and potatoes, though, of course, the quality of sugar beets and potatoes grown on such land may not be quite so good as when grown on upland soil. Since marsh soils as a whole are apt to be cold and affected by local frosts, care should be taken in the selection of crops, especially in northern climates. Here corn and potatoes, for example, might be out of the question. On the other hand, cabbage, rape, turnips, hay, of which a mixture of timothy and alsike clover is perhaps the best, and grain to a limited extent when proper care is taken may be grown to advantage.

EXERCISES, LESSON X.

PROBLEMS.

1. A man had 40 acres of marsh land which produced on an average 1 ton of wild grass per acre, valued at about $3 per ton. He spent $1,000 in draining it. Now those 40 acres raise corn averaging 15 tons of silage corn per acre, valued at at least $3 per ton. Determine this man's interest on his investment.

2. Fifteen tons of manure per acre were applied on a drained peat soil. How many pounds of phosphorus and potassium were applied? How big a crop of corn will this amount of potassium supply?

3. Two hundred pounds per acre of muriate of potash were applied to a muck soil. What was the cost of this application at $46 per ton, and how many pounds of potassium per acre were applied? (See table 24, p. 157, Ref. No. 5.)

4. Compare the value of the manure applied in problem 2 with the cost of the potash fertilizer in problem 3.

5. A portion of a peat marsh was treated with manure at the rate of 15 tons per acre; another portion was treated with an application of 400 pounds of muriate of potash per acre, costing $47 per ton. The first year the manured portion produced 10.5 tons of silage (green) corn per acre, and the second year a yield of 6 tons was secured without any further treatment. On the potash portion the corn averaged 14 tons the first year and 14 tons the second year, without further treatment. Compare the results produced with the cost of manure and fertilizer in this case.

6. On another marsh (muck), an application of a mixture of muriate of potash at the rate of 200 pounds per acre and rock phosphate at the rate of 800 pounds per acre produced 12.5 tons of silage corn per acre. An application of 25 tons of manure on

another portion produced 15.8 tons per acre. The rock phosphate cost $10 per ton and the potash fertilizer $46. How many more dollars' worth of plant food in the manure did it require to produce the gain in yield for that year?

7. A mixture of acid phosphate and muriate of potash in the proportion of 100 pounds to 60 pounds, respectively, was applied to a field at the rate of 150 pounds per acre. The field produced 14.5 tons of silage corn per acre as compared with 3 tons where no treatment was made. The acid phosphate cost this farmer $16 per ton, and the potash fertilizer $45 per ton. What was the cost of this fertilizer treatment, and what may be considered the interest on the fertilizer investment for that year?

A farmer owns a clay farm of 160 acres. For regular cropping purposes he has six 20-acre fields. His crops are alfalfa, corn (two fields each year), oats, wheat, and red clover. The alfalfa occupies a field for five years, then is plowed for corn. The crops on the other fields are, in the order named, corn, oats, wheat, red clover. Rye, or rye and vetch, are used as a cover crop following the crops of corn. The crops are so planned in the five fields not growing alfalfa that each year the farmer has two fields of corn and one field each of oats, wheat, and clover. The analysis of the soil on this farm is fairly uniform and shows per acre in the total 8 inches of surface 4,000 pounds of nitrogen, 2,000 pounds of phosphorus, and 24,000 pounds of total potassium.

8. If C stand for corn, O for oats, W for wheat, and CL for red clover, and A for alfalfa, fill in the blank below so that the order of cropping in each field will be as given above, and so that there will be for harvest each year one field of alfalfa, two of corn, and one each of oats, wheat, and clover.

	Field.					
Year.	1	2	3	4	5	6
1	A					
2	A					
3	A					
4	A					
5	A					

9. Assuming that the plant food liberated from this soil during the average season is equivalent to 2 per cent of the total nitrogen, 1 per cent of the phosphorus and $\frac{1}{4}$ of 1 per cent of the potassium:

(a) From table 23, reference No. 5, page 154, determine whether sufficient of the plant-food elements, nitrogen, phosphorus, and potassium, would be liberated during a growing season on this farm to produce a 100-bushel crop of corn.

(b) Compute whether any of these plant-food elements is present in this soil in sufficient quantity to produce the maximum of any crop noted in table 23.

10. The yields of crops on the farm averages 4 tons of alfalfa hay per acre, 50 bushels of corn per acre with 2 tons of stover, 50 bushels of oats with $1\frac{1}{2}$ tons of straw, 25 bushels of wheat with $1\frac{1}{2}$ tons of straw, and 3 bushels of clover seed per acre with $1\frac{1}{4}$ tons of clover hay the first cutting, three-fourths tons clover straw from hulling, and one-half ton growth of clover to turn under for corn.

(a) If the farmer sells his alfalfa, the grain including the corn, and the clover seed, but returns to the soil all corn stover, straw, and clover; and if each ton of clover fixes in its growth 40 pounds of nitrogen, and each clover crop fixes 12 pounds of

nitrogen per acre from the growth of vetch: Determine the nitrogen balance to the soil of a field resulting from one period of the cropping system, not including alfalfa. (See table 23, Ref. 5, p. 154). What would be the result if cowpeas were grown in the corn and added 30 pounds of nitrogen to the soil each year?

(b) If the farmer feeds to live stock three-fourths of all produce grown, including alfalfa, and uses one-fourth for bedding; and if one-third of the organic matter fed is recovered in the manure, and if three-fourths of the nitrogen and three-fourths of the phosphorus likewise are retained from the feed and bedding; determine the balance of humus and nitrogen to the farm in any period of five years, resulting from this system. (Each ton of alfalfa grown may be considered as fixing 40 pounds of nitrogen from the air.) Compare this balance with the one obtained in (a).

(c) Figure how much phosphorus would be removed from the farm during each 5-year period from both the grain farming and the live-stock farming. How much 6 per cent acid phosphate would have to be added every five years to balance the amount of phosphorus removed?

11. Consider your own system of farming and figure a balance from the standpoints of humus, and the plant-food elements, nitrogen, phosphorus, and potassium.

REVIEW QUESTIONS, LESSON XI.

1. Why has sandy soil little ability to conduct water upward from lower layers?
2. Why is it true that sandy soils may use the water of a light rainfall more efficiently than heavy soils?
3. Explain why topography must be considered more carefully in the case of sandy soils than in the case of clay soils, especially in climates of moderate rainfall.
4. Explain why rolling a sandy soil aids in the germination of fine seeds.
5. In what ways may the injury due to blowing of sand be lessened or prevented?
6. What are the two chief causes of low fertility in sandy soils?
7. How can the nitrogen supply of a sandy soil be best increased and maintained?
8. What advantages has a sandy soil over a heavy soil?
9. What small grains are especially well adapted to sandy soils? Explain.
10. To what classes of crops are sandy soils best adapted?
11. What is meant by heavy clays?
12. Describe how heavy clay soils may be formed. Give examples.
13. Name some of the characteristics of clay.
14. Discuss methods of maintaining good tilth on heavy clay land.
15. Explain why grasses and cereals are best adapted to these soils.
16. Why are heavy soils particularly objectionable for the growing of potatoes?
17. Why do most crops on heavy clay soils respond well to the use of phosphate fertilizers?
18. Why do some clays contain more organic matter than others?
19. When a clay soil is black, does it necessarily mean that it is well supplied with available nitrogen? Explain.
20. Do clay soils ever require lime?
21. What are marsh soils, and how are they formed?
22. Distinguish between muck and peat soils.
23. What factors should govern the construction of open ditches?
24. What precaution should be taken in laying tile in a peat marsh?
25. What are the peculiarities of marsh soils as a class in regard to fertility?
26. Explain why some marsh soils are acid and others are not.
27. How may the fertilizer needs of marsh soil be best supplied?
28. In what ways is the looseness of marsh soils unfavorable to the growth of crops, and how may it be overcome in part?
29. What crops are especially well adapted to marsh soils, and why?

LESSON XI. SOIL ADAPTATION TO CROPS.

Relations between soils and crops (Ref. No. 4, pp. 291–306; or No. 10, pp. 232–256).—There are a number of important relations between the character of the soils and the crops to which they are adapted. The climate also has an important effect, not only directly on the crop, but indirectly through the soil. Certain crops require long growing seasons between frosts, and they are seriously injured by a freezing temperature. The amount of rainfall is likewise an important consideration. Some crops growing very early in the spring and maturing in the early summer require much less water than do those growing during the longer summer season when evaporation, not only from the plant itself, but also from the soil, is at the maximum. Moreover, there is an intimate relation between the water-holding capacity of the soil and the character of the rainfall upon crop production. Soils which have a fine texture and deep subsoil are able to retain nearly enough moisture from the early spring rains to mature crops growing through the summer, provided sufficient care is taken to develop a mulch so as to lessen the surface evaporation. Again, there is a close relation between the texture of the soil and the conditions affecting the quality of the crop, and also the use of tools both in planting and harvesting. All of these matters must be carefully considered. The following paragraphs are intended only as suggestions on some of the more important of these relations as they affect some of the more important crops. Crops may, for this purpose, be grouped into three classes, (1) tilled crops, (2) cereals, and (3) grasses and legumes.

SOILS ADAPTED TO TILLED CROPS.

While tilled crops, such as corn, potatoes, sugar beets, cabbage, etc., differ among themselves in many important respects, they are alike in that they permit tillage of the soil to kill weeds and for the development of a soil mulch to lessen evaporation of water. Most of them also grow through the long summer season, making a large growth, which requires abundant supplies of all the essential elements of plant food.

Corn (Ref. Nos. 7, p. 576; 10, p. 243).—Corn may be grown in any section having a season of 100 days free from frost, but the larger yielding varieties require 120 days, and a maximum growth of this crop occurs only in sections having relatively warm nights. Higher altitudes are therefore not suitable, since they are characterized by cool night temperatures. The larger quantity of water used by heavy crops of corn can be supplied only by soils having large water-holding capacity or in sections where the summer rainfall is relatively large. Hence the best results with this crop are secured on com-

paratively level alluvial soils, which are not so fine in texture as to make tillage for the development of good tilth and conservation of moisture impossible. Sandy loams, loams, and silt loams are therefore better than heavy clay soils. The large amount of nourishment required by this crop can be supplied only by soils having high natural fertility or by the use of fertilizers. The virgin fertility of the rich black prairie soils has proved sufficient to meet the demands of this crop for a number of years after being first broken, but in no case can undiminished yields be expected to continue indefinitely without the application of fertilizers.

The study of the root system of corn is interesting. (Ref. No. 2, pp. 215). As ordinarily planted in rows 3½ feet apart in a deep permeable soil, the roots extend to a depth of 18 inches by the time the crop is 1½ feet high and is about 6 weeks old. Even at this stage the roots meet between the rows so that the entire subsoil is occupied. When the corn has reached a height of 3 feet the roots often extend to a depth of about 24 inches.

Cotton (Ref. No. 7, pp. 695, 696).—Cotton requires approximately 130 days to reach maturity and so is confined practically to the region south of a line running from southern Virginia to northern Oklahoma. The lowland varieties of cotton require a longer season than do the upland varieties. The requirements of cotton for water and fertility are very similar to those of corn, and this crop gives good yields on heavy soils well supplied with organic matter in sections where the rainfall is not too large. This is especially true in Texas. In the Southeastern States, however, the most widely grown varieties give best results on sandy loam soils.

Tobacco (Ref. No. 7, pp. 699–701).—Tobacco is similar to corn and cotton in its fertility requirements, except that it uses somewhat less phosphorus than these crops. It requires large amounts of nitrogen and potassium and must grow rapidly and thoroughly cover the ground in order to develop the self-shading which is necessary to the fine texture of the leaf essential to the production of a good smoking flavor. For this reason the soil must be kept in the highest state of fertility, and there must always be an excess of the essential elements in available form beyond that needed to supply the actual requirements of the growing crop.

The texture of the soil also has an important influence on the quality of the tobacco leaf. The finer textured wrappers are grown only on loams and sandy loams, while the coarser textured fillers may be grown on heavier soils, which produce larger yields, though of a lower grade. Topography has an important bearing on the growth of tobacco, since it influences humidity and danger of storms to which this crop is especially subject. Shallow-dipping valleys in which the

humidity is higher than on hilltops and in which danger of storms is less are especially well suited for this crop.

Sugar beets (Ref. No. 7, pp. 606–608).—With reference to fertility, sugar beets have essentially the same requirements as corn, though it is important to recognize the fact that this crop requires a great deal of hand labor. A highly fertile soil, comparatively free from weeds, is therefore even more desirable for this crop than for corn or cotton. There is a close connection between the climate and the sugar content of the beet. The most favorable conditions are those of relatively cool nights and of very clear, bright weather, especially during the ripening period. These two conditions are combined in the North and in the western prairie States, where the altitude is such as to produce cool nights.

Potatoes (Ref. Nos. 7, pp. 598, 604; 10, p. 254).—While potatoes are similar to corn and sugar beets in their general requirements of plant food, their production on a large scale is chiefly controlled by conditions affecting: (1) Their quality and freedom from the diseases to which they are subject, and (2) the use of tools for planting and digging. The largest yields of this crop may be secured on relatively heavy soils which have high water-holding capacity and ordinarily greater fertility, but on these soils the crop is subject to diseases and can not be planted or harvested as readily as on the lighter sandy loams which permit the use of the digger and do not bake or crack so as to allow sunburn. Hence, this crop is best grown on relatively light soils. When grown on heavier soils and in a region of heavy summer precipitation a ridged system of culture is best, but on the lighter soils and wherever summer rainfall is not excessive flat culture is preferable.

Scab and other fungus diseases to which the potato is subject develop more often on soils of neutral or alkaline reaction than on those which are acid, and hence, as before stated, the use of lime for the correction of soil acidity is not desirable on the potato crop, or if used on land on which potatoes are to be grown it should be applied on the crops from one to three years before the potatoes are grown.

Cabbage and celery (Ref. No. 7, pp. 625, 628).—These crops are similar in that they require large amounts of nitrogen, potash, and water for their growth. Muck soils meet the requirements in regard to nitrogen and water and require chiefly the use of potash fertilizers to meet the demands of these crops.

Melons, cucumbers, tomatoes, etc. (Ref. No. 7, pp. 614–637).—These crops are similar, especially in that they require unusually warm soils and so are especially adapted to sandy loams. The fertility of these soils can be maintained only through the use of relatively large quantities of fertilizer, which should be applied in the form of organic matter, such as barnyard manure and dried blood, as far as possible.

SOILS ADAPTED TO CEREALS.

(Ref. No. 7, p. 574.)

The most important cereals are similar in regard to their root systems, which are much finer than those of crops which are commonly intertilled. They are also similar in that their growth takes place early in the season and they are therefore able to take advantage of the moisture which has accumulated during the winter. Hence they may be grown in sections of relatively low rainfall, in which the summer is quite dry.

Oats (Ref. Nos. 7, pp. 587–589; 10, p. 241).—Oats are especially adapted to a northern climate and have a relatively strong root system, going 50 per cent deeper than other grains. Varieties have been developed which are adapted to different types of soil. The Kherson or sixty-day oat, for instance, is especially well adapted to marsh land, because of its strong stem which prevents it from lodging on a soil on which crops are naturally very subject to that difficulty.

Rye (Ref. Nos. 7, pp. 585–587; 10, p. 243).—Rye has been developed chiefly in climates of relatively light rainfall, and this, together with the fact that it is sown in the fall and attains considerable root development then, permitting it to mature quickly the succeeding spring, makes it fairly profitable on sandy soils low in water-holding capacity and in sections of the country having a light rainfall.

Wheat (Ref. Nos. 7, pp. 581–585; 10, pp. 234–241).—On account of the fact that wheat has been more widely grown for human food and over a much larger part of the earth than other cereals, it has developed the power of adapting itself to a greater variety of conditions than other grains. It grows in countries with very hot climates as well as in almost the coldest climates permitting growth of agricultural crops. Some varieties will do well with very high rainfall, while others are adapted to regions of very low rainfall. While it can be grown on many different kinds of soil, wheat is best adapted to relatively close-textured soils, such as silt and clay loams.

SOILS ADAPTED TO GRASSES AND LEGUMES.

(Ref. No. 7, pp. 536–573.)

True grasses, especially those used for pasturage and hay, are characterized by very fine root systems. They differ also from most other cultivated plants in that they grow continuously through the entire growing season and therefore require a more uniform distribution of moisture than is essential to crops growing only early in the spring or during the midsummer period. The extremely fine root systems of these plants adapt them especially to clay soils, which they are able to permeate and from which they can extract the large supplies of moisture which these soils are able to hold.

Legumes, such as clovers, soy beans, and cowpeas, on account of their ability to secure nitrogen from the atmosphere, are of particular value for growth on soils low in organic matter. They include annuals and biennials of wide range of resistance to drought and frost, so that a selection can be made of those which are best adapted to almost any conditions, and every farmer should see to it that he has thoroughly mastered the growth of one or more legumes in such a way as to maintain the nitrogen and organic matter of his soil at its highest state.

EXERCISES, LESSON XI.

(a) Draw a map of the United States, or secure outline maps having State lines, then locate and label the important corn, wheat, potato, sweet potato, cotton, tobacco, and flax sections by States. Use the Yearbook of the Department of Agriculture for 1913 to select the States, as follows:

Corn.—Select five States having highest acreage, page 372.

Wheat.—Select five States having highest acreage, page 381.

Potatoes.—Select eight States having highest acreage, page 411.

Sweet potatoes.—Select six States having highest acreage, page 414.

Cotton.—Select six States having highest acreage, page 423.

Tobacco.—Select five States having highest acreage, page 428.

Flax.—Select five States having highest acreage, page 434.

(b) Discuss the relation of climate, soils, and rainfall in these sections to the various crops named. Consult this lesson, Ref. No. 7, pp. 574–710, and any good general cyclopedia.

REVIEW QUESTIONS, LESSON XI.

1. Name some of the factors which determine the adaptability of crops to soils.
2. Discuss the relation of corn growing to the climate conditions of the Mississippi Valley.
3. What influence has texture of the soil on the quality of tobacco?
4. Mention three conditions of soil or climate essential to success in raising sugar beets.
5. For what reasons are potatoes best grown on sandy loam soils?
6. Explain the relation between fungus diseases of potatoes and the chemical reaction of the soil.
7. What are the special requirements of cabbage and celery?
8. What conditions of soil are best adapted to the growing of melons and cucumbers?
9. Explain why grasses are able to grow better on heavy clay soils than root crops can.
10. On what principle does the classification of soils into grass soils, grain soils, and truck soils rest?

LESSON XII. CROP ROTATIONS AND SOIL FERTILITY.

(Ref. No. 4, pp. 273–283; or No. 6, pp. 356–372; or No. 7, pp. 505–507; or No. 10, pp. 298–300.)

Although it is easier to learn to grow one crop well than to learn to grow several crops well, nevertheless, there are distinct reasons why it is best to grow more than one crop on most farms. It permits a more economical and efficient use of labor; it involves less chance of failure, which may be entire in case of loss of a single crop grown;

it permits the growth of crops on different kinds of soils occurring on the farm; and, most important, it permits a cropping system whereby soil fertility may be improved.

Advantages of rotation to the soil.—The advantages of a rotation of crops or cropping systems in its relation to fertility are (1) it permits the use of manure on those crops to which it is best adapted; (2) it aids in preventing diseases or other unfavorable conditions which may develop on soil kept continuously in one crop; (3) it permits tillage calculated to improve the tilth; (4) it aids in the eradication of weeds; and (5) it permits the growth of crops which will result in an addition of humus and nitrogen to the soil.

We have already seen that raw manure can be used to much better advantage on certain crops, especially such rank-growing crops as corn, sugar beets, cabbage, and cotton, which permit intertillage, than on small grains or many of the vegetables.

The advantages of a rotation of crops in lessening diseases are becoming more and more apparent as our agriculture becomes more fixed. The growth of any cultivated plant on a given area or even in a given neighborhood continuously for a number of years is almost invariably followed by the appearance of some specific diseases or insect enemies, which are attached in one way or another to the soil on which the crop is grown. The development of the corn-root fungus, the cabbage diseases, the flax-wilt diseases, and many others which might be mentioned are evidences of this fact. While many of these diseases can be treated with specific remedies, applied to the seed before sowing or to the plant in the proper stage of development, it is nevertheless a very great aid in reducing difficulties of this kind to have the crop grown but one or two years on a given piece of land and then have it followed by other crops not subject to the same diseases.

Good tilth may be much more readily maintained on soils difficult to work by a rotation of crops than when the same crop is grown continuously. For example, the use of heavy clay land for meadow and pasture, in which the development of sod occurs makes it much easier to keep such soil in good tilth than when it is kept continuously in tilled crops.

A large part of the labor of land tillage is concerned in the eradication of weeds. A rotation of crops greatly aids in this matter. Some weeds are entirely unable to withstand the crowding of grasses, and the use of land as meadow and pasture will naturally kill them. Others, on the contrary, develop under these conditions and can be removed only when the land is in tilled crops which permit cultivation. The planning of any rotation must take into account the eradication of noxious weeds when these constitute a serious difficulty on the farm.

Probably the most important object of the rotation of crops on a large part of the best agricultural land of this country is concerned with the maintenance and increase of humus and vegetable matter in the soil. (Ref. No. 4, p. 275.) Increase of humus in the soil takes place when crops are grown which are not intertilled and have fine root systems permeating even compact soils. The use of land as meadow and pasture is, therefore, one of the most effective ways for adding to the humus content of the soil. If the meadow or pasture contains legumes, the nitrogen as well as the humus content is increased.

Planning the cropping system.—To gain the advantages mentioned above, a rotation of crops must be very carefully planned. The essential parts of the rotation consist in (1) intertilled crops, (2) grain crops, and (3) grass and legume crops to be used either as hay or pasture. But in working out the plan for rotation the farmer must consider not only the crops to be grown, but the relative yield of each, since it is necessary that the farm be laid out in fields of essentially uniform size. On an 80-acre dairy farm, for instance, the farmer might wish to grow corn, oats, or other grain, clover, and have some pasture. While the best division of the farm among these crops might be an even one, it is necessary to adjust the total yields of the several crops grown until the division of the farm into fields of equal size is practicable. It is possible, however, to grow any of these crops more than one year on the same piece of land in a single rotation, so that if it is desired to have more than one-fourth of the land in corn, that can be arranged by growing this crop two years in succession, or if more grain is desired the same method may be used. Again, a large number of farms include unimproved land, which can be used as permanent pasture but can not readily be brought into the rotation with other crops.

Relation of rotation to type of soil.—Each type of soil must be considered separately with reference to the rotations for which it is best adapted. (Ref. No. 7, p. 506.) On sandy soils short rotations give better results than long rotations. As far as practical, at least one-third or one-fourth of the soil of a sandy farm should be in a legume or other crop, part or all of which is to be turned under for green-manuring purposes. On one of the best potato farms in Wisconsin the following rotation is practiced: First, potatoes in which rye is sown ahead of the potato digging, so that it makes a good start in the fall, and then timothy. Clover is sown and dragged in the following spring. This gives a 3-year rotation of potatoes, rye, and clover. Practically all of the clover is plowed under as a green-manure crop. In this way the soil is kept well supplied with active organic matter, and the sand is protected from blowing by the rye in the fall and spring.

On heavier soils, where grain and stock raising is practiced, a longer rotation is usually desirable, especially if some of the cultivated land is also to be used for pasture. A 6-year rotation can then be worked out, such as the following: Corn, wheat, oats, clover, timothy, and pasture, or it can be shortened to five years by omitting either one of the grains or the pasture year.

Rotation for different types of soil on the same farm.—Over a considerable part of the United States there is such a variation in soils within short distances that the relation of one type of soil to the other must be fully considered. When a farm includes sand and marsh soils which have been drained and brought under cultivation, all of the manure should be used on the sandy soil, since the marsh soil does not need nitrogen, and can be kept in a high state of fertility through the use of moderate quantities of commercial fertilizers containing potassium and phosphorus, thereby making it possible to keep the fertility of the whole farm in a high state. The same method may be used when the farm includes clay and marsh soils. In such cases it may be necessary to develop two or more systems of rotations on a single farm. All of these matters must of course be worked out with reference to each particular case, and the success of the farmer depends to a considerable extent on his judgment in working out logical systems of cropping adapted to his soil conditions as well as to his market and other factors affecting his work.

Rotation systems for permanent fertility (Ref. No. 5, Chaps. XV and XVI, pp. 226–235).—After all, it must be recognized that the most important problem in any system of farming is so to conduct the cropping and the disposition of the crops that the fertility of the soil shall not alone be maintained, but that it shall be constantly built up in the best and most profitable manner. Herein lies one of the most vital parts of good farm management. The somewhat prevalent idea among farmers that simply rotating crops will improve, or even maintain, the fertility of soil is without a safe foundation. It is true, for reasons stated in the beginning of this lesson, that far better results in cropping will be realized from a well-planned rotation than from a single-crop system. But actually to build up the fertility of a soil one should first understand what elements of plant food are low in the soil, then the cropping system, the type of farming, the building up of humus and mineral elements through manures and fertilizers, and the physical management of the soil should all be so studied and planned that gradual soil improvement will result. The management necessary to attain this end will vary, of course, with the system of farming practiced.

In vegetable gardening, manure from cities can usually be secured in quantity, and the soil can be improved while profits are realized from the crops by the purchase of both stable manure and com-

mercial fertilizers. In fruit farming, it is generally necessary for soil improvement to grow legume crops to return to the soil as well as to add the mineral elements which are low in the soil by using fertilizers. In grain farming, if fertility is to be maintained or increased, the grain, including small seed, may be sold, but all roughage, including cornstalks and straw from grain and seed, should be returned to the soil; besides, a legume crop like red clover should be grown once in three or four years as a green manure to furnish vegetable matter and nitrogen to the soil, while mineral elements not plentiful in the soil should be regularly added to provide for what is removed from the sale of grain. It should be remembered also that phosphorus is removed from the farm in large quantity in grain farming. In live-stock farming, where the manure is well cared for and returned to the soil without much loss, the humus and nitrogen content of the soil can be built up where sufficient leguminous crops are grown in the rotation to furnish the feed of this kind necessary for the best results with the live stock. However, it will still be necessary to return some mineral elements, especially phosphorus, in order to increase the fertility of the soil.

EXERCISES, LESSON XII.

ROTATION PROBLEMS.

1. Plan a system of crop rotation on an 80-acre sandy farm, potatoes being the main crop.

2. Plan a rotation for farming on a 120-acre sandy farm. The following crops are to be grown each year as far as possible: Corn, 25 acres; rye, 12 acres; oats, 15 acres; clover, 25 acres; alfalfa, 10 acres; potatoes, 4 acres; tomatoes, 2 acres; and melons, 2 acres. Five acres are allowed for buildings, etc., and 20 acres for pasture.

3. Describe a plan for treating the soil in problem 2—use of manure (200 tons), commercial fertilizers, liming, and inoculation.

4. Suppose the sand on one of the forties in problem 2 is subject to blowing by the wind, will that make any change in the plan for rotation? Work out a plan of crop rotation under these conditions.

5. Suggest a plan for rotation on a sandy soil on which potatoes, tomatoes, melons, and onions are the principal market crops.

6. Plan a rotation on a southern sandy plantation of 200 acres where peanuts are an important crop. Other crops grown are cotton and corn. (Ref. No. 7, pp. 695–710.)

7. A man owns the W. $\frac{1}{2}$ and the SE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ of a section of land. Locate this land in the section.

8. All of this land in problem 7 is level and under cultivation. Each year he raises 40 acres of corn, 20 acres of clover, 20 acres of timothy, and 40 acres of oats in a 3-year rotation. Outline his system of rotation.

9. A farmer has a farm including the SE. $\frac{1}{4}$ of the NW. $\frac{1}{4}$; the SW. $\frac{1}{4}$ of the NE. $\frac{1}{4}$; the NW. $\frac{1}{4}$ of the SE. $\frac{1}{4}$; and the NE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ of a section. His farm buildings, orchard, and garden take out 5 acres in the NW. corner of the NW. $\frac{1}{4}$ of the SE. $\frac{1}{4}$. This land is all level, silt loam. In order to meet his requirements he wants to raise each year 40 acres of corn, 40 acres of hay (30 of clover and 10 of timothy), 30 acres of oats, 10 acres of barley, 5 acres of potatoes, and 30 acres of pasture. Plan a system of crop rotation.

10. If 300 tons of manure are produced on the farm annually, in problem 8, how can this manure be most economically used?

11. A man owns the W. ½ of the NW. ¼ of a section of land. On the north end 20 acres are taken out of the crop-producing portion of the farm on account of woodlot, farm buildings, and railroad right of way. Each year this man raises 20 acres of corn, 20 acres of oats, and 20 acres of hay (5 of alfalfa and 15 of a mixture of clover and a little timothy). A 3-year rotation is practiced, with the exception of alfalfa, which is left four years. Draw a diagram showing how this man rotates his crops.

12. A farm located in the S. ½ and the NE. ¼ of the SE. ¼ of a section contains 20 acres woodlot in the W. half of the NE. ¼, 10 acres of hillside subject to erosion in the NE. ¼ of the NE. ¼, and 20 acres of acid sandy soil at the west end of the S. ½. Five acres in the SE. corner of the farm are taken out for buildings. Plan a system, or systems, of rotation on this farm when the following crops are to be raised each year as far as possible: 30 acres of corn, 20 acres of oats, 10 acres of barley, 10 acres of alfalfa, 15 acres of clover, and 30 acres of pasture, including woodlot.

REVIEW QUESTIONS, LESSON XII.

1. Give specific reasons why it is best to grow more than one crop on a farm.
2. Name five advantages derived from a crop rotation.
3. What is understood by tilled crops? Intertilled crops?
4. Explain how grasses are better adapted to humus formation than cultivated crops.
5. Name the essential parts of a rotation.
6. What determines largely the kind of rotation a farmer may practice?
7. Discuss the rotation best suited to a sandy farm.
8. Suggest a 6-year rotation for a dairy farm. A 5-year rotation.
9. On a farm consisting of sand and marsh, where can manure be used to best advantage? Why?
10. Discuss the relation of different types of soils in a farm to crop rotations.
11. Outline a cropping system and a plan of fertilization for grain farming whereby the fertility of the soil of the farm may be maintained or increased.
12. Compare grain farming with live-stock farming from the soil-fertility standpoint.
13. What is the most important problem in connection with permanent agriculture.
14. Are you now able to figure out accurately a profitable system of cropping and fertilization whereby the fertility of your farm will gradually be increased?

APPENDIX.

REFERENCE BOOKS.

The publications here listed are specifically referred to in the text and must be consulted in order to obtain the information purposely omitted in the bulletin because of want of space. This library of reference books will be supplied by the State agricultural colleges and loaned by them as a unit to each class.

1. First Principles of Soil Fertility. Alfred Vivian, 1906.
2. The Soil. F. H. King. 1896.
3. Soils, Their Properties and Management. T. L. Lyon, E. O. Fippin, and H. O. Buckman, 1915.
4. Soils and Fertilizers. Harry Snyder, 1908, 3. ed.
5. Soil Fertility and Permanent Agriculture. C. G. Hopkins. 1910.
6. The Fertility of the Land. I. P. Roberts. 1909, 3. ed.
7. Fertilizers and Crops. L. L. Van Slyke. 1912.
8. Practical Farm Drainage. C. G. Elliott. 1908, 2. ed.
9. Chemistry and its Relations to Daily Life. Louis Kahlenberg and E. B. Hart. 1913.
10. Dry Farming. J. A. Widtsoe. 1913.
11. Yearbook of the United States Department of Agriculture. 1913.
12. Manures and Fertilizers. H. J. Wheeler. 1913.
13. Soils. E. W. Hilgard. 1910. To be included when classes are conducted in arid regions.

Any unabridged dictionary.

LIST OF APPARATUS AND SUPPLIES REQUIRED.

APPARATUS.

12 Coddington or other cheap hand lenses.
12 long pickle bottles with corks.
6 wide-mouthed bottles with corks.
24 one-inch cubes.
6 two-gallon crocks or jars.
6 one-pint glass fruit jars.
6 jelly glasses.
1 balance with weights.
12 one-pound baking-powder cans.
2 measures graduated for cubic inches.
2 small mortars and pestles.
6 one-quart glass fruit jars.
6 tin cups.
6 pie tins.
6 shallow dishes (saucers).
6 pieces of ¾-inch or 1-inch glass tubing (2 feet long).
6 feet small-sized glass tubing.
3 three-inch unglazed tile.
4 wooden boxes, 1 foot square and 4 inches deep.
6 small Fahrenheit thermometers.
1 marble slab, 1 foot square, polished on on both sides.
4 three-gallon crocks.
24 outline maps of the United States.
6 porcelain dishes.
12 one-hole stoppers.
6 feet rubber tubing.
1 set of soil sieves.
Cheesecloth.
1 package small needles.

SUPPLIES.

Specimens of common rocks as follows: Granite, schist, shale, slate, limestone, marble, sandstone, quartzite, feldspar, hornblende, quartz, black and white mica, calcite, gypsum.
1 pound paraffin.
4 ounces muriatic acid.
1 quart powdered limestone.
Several small pieces limestone.
1 quart sodium nitrate.
1 quart muriate of potash.
1 quart sulphate of potash.
1 quart ammonium sulphate.
1 quart kainit.
1 quart acid phosphate.
1 quart rock phosphate.
1 quart bone meal.
4 ounces ammonium carbonate.
4 ounces marble dust.
6 packages each of red and blue litmus paper.
1 pound lump sugar.
1 pound powdered sugar.
6 sticks sodium hydroxid.
1 quart burnt lime.
1 stick sealing wax.

NOTE.—The apparatus and supplies have been estimated for a class of twelve. Ordinarily two people will work together in laboratory practice, and the quantity of apparatus and supplies may be varied to suit the size of the class. The different soils needed should either be furnished as a part of the supplies, or else arrangements must be made for the class to secure and dry them before the work of the course is begun.

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